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The Journal of Bone and Joint Surgery

The Official Publication of
The American Orthopaedic Association
The British Orthopaedic Association
The American Academy of Orthopaedic Surgeons
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Editor, WILLIAM A. ROGERS, M.D.
Assistant Editor, FLORENCE L. DALAND
8 The Fenway, Boston 15, Massachusetts, U. S. A.

British Editorial Secretary, MR. H. JACKSON BURROWS, F.R.C.S., F.R.A.C.S.
45, Lincoln's Inn Fields, London W. C. 2, England

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The Journal of Bone and Joint Surgery

EDITORIAL ANNOUNCEMENT

Beginning in January 1948, the scope of *The Journal of Bone and Joint Surgery* will be extended. Surgeons throughout the English-reading world will be able to keep in closer contact with each other's work in orthopaedic surgery through a single, jointly edited and administered journal. They will find recorded on the pages of their *Journal*, the progress and trends in orthopaedics, not only in their own, but in other countries.

Techniques, fundamental clinical studies, and advance in the basic sciences will be recorded from a wider circle of contributors, of more diverse background, than heretofore. These articles will appear not alone as contributions to world orthopaedic surgery; national individuality will be retained.

The American Orthopaedic Association, in conjunction with The British Orthopaedic Association and The American Academy of Orthopaedic Surgeons, sponsor this extension of the scope of *The Journal*.

The British Editorial Board under the auspices of The British Orthopaedic Association will be representative of orthopaedic surgery throughout the British Commonwealth of Nations. The British Editor is Sir Reginald Watson-Jones.

As representative of orthopaedic surgery in the United States of America, the American Editorial Board will be appointed from the membership of The American Orthopaedic Association and the fellowship of The American Academy of Orthopaedic Surgeons.

The American and the British Editorial Boards will be enlarged to a membership of sixteen each. More adequate representation, geographically, becomes possible on the larger Boards. Wider diversity of attainment and discipline, as well as the viewpoints of younger men, will be needed in shaping the future work of *The Journal*. Through more representative Boards, these needs may be met. Collaboration in the broader aspects of policy and correlation of activities of the two Boards will be possible through joint meetings.

The Journal, at present a quarterly, will be published in eight issues. In this larger *Journal* there will be increased space for the publication of significant articles. Four of the eight numbers will be edited and published in Great Britain (the British Volume), and four in the United States of America (the American Volume). Through separate volumes, postal regulations can be met.

Issues of the United States and of the British Commonwealth will appear alternately, at six-week intervals throughout the year, and will be mailed directly to the subscriber from the respective offices of publication.

The subscription price of the two volumes will be $14.00 or £3.10.0, postage prepaid.

Articles submitted for publication from all nations will, as heretofore, be welcome. Such articles are earnestly solicited, and may be submitted to either the American or the British Editorial offices of *The Journal*.

WILLIAM A. ROGERS, *Editor*

ORTHOPAEDIC SURGERY AND ITS PLACE IN THE DEPARTMENT OF SURGERY IN OUR MODERN MEDICAL SCHOOLS*

BY LEROY C. ABBOTT, M.D., SAN FRANCISCO, CALIFORNIA

The first point that I would like to stress is the extraordinary advance that has been made in orthopaedic surgery since the foundation of The American Orthopaedic Association in 1887. While the pioneers in this field undoubtedly envisioned the ever-widening scope in our branch of surgery, I do not believe that they could have foreseen the tremendous development that has taken place. At the present time, orthopaedic surgery represents the largest special field in the department of surgery in most of our medical schools. In the majority of these schools, surgery is divided into so many specialties that the so-called department of general surgery is practically non-existent. It, too, is a specialized line, confined largely to surgery of the abdomen and neck. Nevertheless, under the guise of general surgery, this special branch has maintained control and continues to dominate the entire department of surgery. It is possible that this state of affairs may have been desirable during the early period of our development, but changing conditions have made this domination by a single branch no longer practical or justifiable.

Orthopaedic surgery has come of age and can stand on its own merits. It does not require the guiding hand of any other branch of surgery and, in my judgment, this persistent domination simply has the effect of hampering progress in our field.

These conclusions have not been arrived at hastily, but quite the contrary, being based on personal observation and experience as a student, teacher, and surgeon over a period of thirty years, not only in orthopaedic surgery, but also in general surgery, before specialization was so highly developed. During that time I have had the privilege of promoting the growth of orthopaedic surgery in three of our leading medical schools: California, Michigan, and Washington University in St. Louis. I am entirely in agreement with the idea, advocated by outstanding men in all fields of surgery, that a broad general training and background should be prime requisites to entering a specialized field. Furthermore, the opinions set forth in this paper are not prompted by bias on my part, since my own experience has been most fortunate, especially during the past sixteen years. Conditions have been extremely favorable, because Dr. Howard Naffziger, Professor of Surgery at the University of California Medical School, who is a specialist in his own line of neurosurgery, with an excellent background of training and experience, has very liberal ideas in regard to other branches of surgery.

However, orthopaedic surgery still remains a subdepartment in most of our medical schools, and the heads of such departments do not have the same jurisdiction as the chief of the division of general surgery in decisions involving policies of the medical school, and the arrangement of the curriculum for teaching undergraduate and postgraduate students; nor do they, in most instances, have direct contact with the dean of the medical school as members of the dean's executive committee. Moreover, they do not have complete control of the appointments and promotions in their own departments, nor do they have proper representation in the distribution of the budgets. In the appointment of interns and assistant residents in surgery—in other words, of the men who are chosen for the basic and broad training of surgery—the advice of the head of a subdepartment is seldom sought; neither does such advice, if sought, receive authoritative attention. In no way does the head of a subdivision have equal status with the head of the division of surgery.

At this point it might be interesting to trace the history of orthopaedic surgery from

* Presented as the President's Address at the Annual Meeting of The American Orthopaedic Association, Hot Springs, Virginia, June 29, 1947.

its humble beginnings up to its present highly developed skill. One of the great masters of surgery, Sir Robert Jones, has defined orthopaedics in the following terms: "The treatment by manipulation, operation, re-education, and rehabilitation of the injuries and diseases of the locomotor system". This comprehensive definition of the scope of orthopaedics is a far cry from the modest efforts of the early bone-setters, and it serves to emphasize the infinite possibilities of modern orthopaedic surgery.

Although the Frenchman, André, as early as 1741, defined the term "*orthopaedia*" as the art of preventing and correcting deformities in children, orthopaedics was not taught as a specialty until 1887, and its modern development can be traced to the foundation of The American Orthopaedic Association. For the first fifteen years of its existence as a special field, our activities were confined largely to the use of mechanical appliances, and our contemporaries in other medical branches referred to us as "the buckle-and-strap men". Willard, in his Presidential Address of 1935 before this Association, speaks of this period of the treatment of deformity by mechanical means. He further states that, in the Annual Meeting of 1893, only one paper out of thirty-one dealt with surgical procedures, and even such subjects as "A New Method of Curing Soft Corns" and "The Mechanical Treatment of Ingrown Toenails" were discussed by eminent men.

Previous to 1900, the only major surgery advocated was destructive in character, excision of the hip for tuberculosis being frequently mentioned. With the turn of the century, however, more constructive types of operation were developed, and operative correction of deformity arising from a variety of conditions became more general. Brackett, in 1905, pointed to the enlarged scope of orthopaedic surgery, which had then come to include the treatment of adults as well as of children. These advances in orthopaedic surgery have kept pace with modern surgical advances in other branches. In 1911, Albee introduced the use of the bone graft in the treatment of tuberculosis of the spine, and during the next few years extended its application to include ununited and malunited fractures. During this same period, Gallie and Phemister did their pioneer experimental work with bone grafts, which added to our fundamental knowledge of how results were obtained. Gallie demonstrated his work at the Massachusetts General Hospital in Boston in 1915, when Smith-Petersen and I were serving as house officers on the Orthopaedic Service. Our chief was Dr. Elliott Brackett, a splendid surgeon, while the assistant chief was Dr. Robert Osgood, a great teacher and inspiring leader. Among many operations performed by them were fusions of the spine and of the joints in tuberculous conditions, the application of bone grafts in ununited fractures, arthrodesis of the hip for arthritis, tendon transplantations, and a variety of operations for infantile and spastic paralysis. The effect of faulty posture in the production of back strain, particularly of the lumbosacral and sacro-iliac joints, was demonstrated by Goldthwait. Various deformities resulting from arthritis were corrected in the orthopaedic wards. But fresh fractures were considered as solely within the province of the general surgeon, who exercised every precaution to prevent the orthopaedic surgeon from taking part in their treatment, unless complications arose,—such as malunion or non-union. I well remember the critical attitude assumed by one of the senior members of the general surgical staff, because a fracture of the neck of the femur had been treated on the Orthopaedic Service, when he felt that a state of non-union had not yet developed. It was on this case and several others following that Brackett developed the now well-known "Brackett operation" for non-union in fractures of the neck of the femur. About this time, my valued friend, Smith-Petersen, because of his dissatisfaction with the methods of exposure then employed, developed his approaches to the hip and the sacro-iliac joint. These were the first of many original contributions made by him.

During World War I, great strides were made in orthopaedic surgery. It was my good fortune to witness these at close range, having been sent to Great Britain as one of the first twenty orthopaedic surgeons who served under the Military Director of Orthopaedic

Surgery, Sir Robert Jones. The Edinburgh War Hospital was my assignment. Sir Harold Stiles was the Surgeon-in-Chief, and he directed a tremendous amount of reconstructive procedures and operations on tendons, muscles, bones, and joints. He was recognized as one of the world's greatest surgeons, and it was not only a privilege to assist him, but it was a revelation to witness his delicate and meticulous dissections which covered the whole field of surgery. It was from him that I first learned the vital importance of an intimate knowledge of anatomy in orthopaedic surgery, and the necessity for a broad general training. His own period of training went back to the days when he was a spray clerk in the surgical amphitheater of the great Lister.

From Edinburgh I went to London to work in the British War Office with Sir Robert Jones. This association with a man of genius was a priceless experience. My good friend, Dr. Robert Osgood, was instrumental in securing this appointment for me, and I cannot refrain from expressing my gratitude to him for his friendly interest, as well as my admiration for the splendid work he did in the organization of orthopaedic centers, as second in command to Sir Robert Jones.

Early in the War, Sir Robert saw the need for immediate and adequate splinting of all fractures on the battlefield, and particularly of compound fractures of the femur. He initiated the use of the Thomas splint in No Man's Land, and you are all familiar with the results achieved. Furthermore, he realized that fractures of the femur were kept in general hospitals in France for too long an interval after injury and consequently could not have the proper definitive treatment. A review of the records of many such patients after they had been sent back to England almost invariably showed an alarming proportion of deformity and shortening. He was responsible for the institution of early removal to fracture centers in Great Britain, where definitive care could be carried out and the fundamental principles of traction and countertraction for restoration of length and alignment could be applied with splendid results.

Other developments in orthopaedic surgery at this time are notable examples of the vision and leadership of Sir Robert Jones. He felt very strongly that the problem of the wounded soldier consisted not only in the immediate care of his injury, but in the complete reconstruction of his mind and body by re-education and rehabilitation. This led to the development of departments of physical and occupational therapy, the latter principally in the form of Curative Workshops. These were created in all British orthopaedic centers. The work accomplished by Sir Robert in this connection aroused so much admiration that he was able to enlist the support of many devoted volunteers, among them the exiled King Manuel of Portugal, who was living in England at that time. In order to stimulate wide general interest in this curative work, Sir Robert established a magazine, appropriately named *Recalled to Life*, which was edited by Lord Charnwood, well remembered for his excellent biography of our own Abraham Lincoln. Later the name was changed to *Reveille*, and it was then edited by the celebrated English novelist, John Galsworthy.

The various orthopaedic hospitals in Great Britain were in charge of leaders in the field of general surgery, all under the directing guidance of Sir Robert Jones.

My second year of service in the Army was spent in several hospitals in France. In the first one, in Paris, the fractures were received directly from the front after first-aid treatment and splinting had been carried out. Therefore, I was able to observe these patients from the very beginning, through their definitive care, and up to the time they were ready for evacuation. These observations left indelible memories. First, I saw the inadequacy of débridement of the wounds by doctors who lacked an accurate knowledge of anatomy. Then I saw the failure to produce length and alignment in compound fractures, because of the use of complicated and altogether unmanageable apparatus. Sepsis was rampant among our war-wounded in those days and was due, in many instances, to faulty and inadequate treatment of the wounds and the neglect of fundamental principles of dependent and adequate drainage, as well as to defective immobilization.

Later in the War at Savenay, a collecting base for evacuation to this country, the same conditions prevailed, but on a larger scale. Compounded fractures were treated inadequately, and the fundamental principles that we had used in England were not generally applied. However, under the dynamic leadership of Colonel Goldthwait, the necessary changes were rapidly made. Men with fractures were placed on the Orthopaedic Service, where the treatment consisted in the application of adequate splinting and immobilization, the institution of proper dependent drainage, and the meticulous care of the wound. They were cared for in special wards, depending on the anatomical location of the injury. Patients with amputation stumps were also segregated, and nearly all of these amputations were of the guillotine type. They were treated by splinting and traction to prevent deformity of the adjacent joints, and in order to gradually pull the skin over the end of the stump. Early ambulation with temporary prosthesis was also used effectively. I was greatly impressed by the amazing results accomplished through the universal application of these simple fundamental principles of orthopaedic surgery.

My third year of experience and observation abroad was not spent in Army hospitals, as I returned to Edinburgh for further training in general surgery under my former chief, Sir Harold Stiles. For the first six months, my assignment was that of Resident-Surgeon at Chalmers Hospital and assistant to Sir Harold in his private practice. During the latter part of my stay I was Resident-Surgeon in the Royal Infirmary under Sir Harold, who had then been appointed Regius Professor of Clinical Surgery, a post formerly held by such illustrious men as Syme, Annandale, and Lister. In the Royal Infirmary, our wards were filled with all types of cases and general surgery was *actually general*, because specialization was practically non-existent. Our operations included the fields of neurosurgery, chest surgery, genito-urinary surgery, orthopaedic surgery, and surgery of the abdomen and neck. Sir Harold foresaw the inevitable necessity for specialization, because of the rapid developments in surgery, and he insisted on the need for placing the treatment of fractures on a different basis. Our wards were the first to possess adequate equipment, including splints, overhead frames, and fracture tables, for modern orthopaedic treatment. The use of plaster-of-Paris and the technique of its application were introduced in these wards, and I often smile when I recall the reproachful remarks of Mr. Alexander, the keeper of supplies, when he accused me of using more plaster-of-Paris in six months than had been used in the Royal Infirmary during the previous thirty years. This period was really the beginning of the evolution of modern orthopaedic surgery in the Royal Infirmary of Edinburgh. Sir Harold Stiles immediately perceived the significance of this trend in surgery; and, upon his insistence, a lectureship in orthopaedics was established in the University of Edinburgh Medical School.

Following World War I, a number of younger general surgeons who had done some orthopaedic work in Europe during the War decided to specialize in orthopaedics and devoted considerable time to further training when they returned to this country. These men have made fine contributions, both in the laboratory and in clinics. With the increase in the scope of orthopaedic surgery, many able men have been attracted to it. In 1933, The American Academy of Orthopaedic Surgeons was established to provide a forum where they could discuss their common problems and maintain first-hand contact with the developments that were being made. The Academy has done much to promote the advance of orthopaedic surgery by its scientific programs, instructional courses, and technical and scientific exhibits.

In addition, The American Board of Orthopaedic Surgery was created in 1934 for the purpose of elevating the standards of orthopaedic training and the qualifications for practice. With the advent of World War II, the orthopaedic surgeon came into his own in the care of injuries and infections of the bones and joints. Moreover, the treatment of amputations was assigned to him in specially organized amputation centers.

At the present time, our field has become so extensive that, as stated by Gill in his

Presidential Address of 1944, "it seems not improbable that various specialties will develop within orthopaedic surgery, as they have in general surgery"; and, as Steindler has said, general medical knowledge is so essential that we should be called orthopaedic physicians, since the term orthopaedic surgeon has become inadequate. He adds also, that that part of physiology covering the mechanics of locomotion is still virgin soil.

With our growth, we must accept increased responsibility. It is the duty of the older men, with broad clinical experience in the care of fractures, to insist that fundamental principles of treatment should be employed with the application of the simplest apparatus that is feasible. The routine use of complicated contrivances which involve penetration of the bone with multiple pins should be avoided. These should be reserved for special cases, where experience has shown that they are absolutely necessary. Complications, some of them serious, are of frequent occurrence in their use, particularly in the hands of the uninitiated. It is common knowledge that the majority of fractures can be successfully treated by the older and more conservative methods without taking unjustifiable risk. As Ryerson has so well put it in a recent article: "The best fracture surgeon uses the fewest gadgets".

The practice of surgery as a specialty in the general field of medicine began about the time of the founding of the American Surgical Association in 1880. Coller, in his Presidential Address before that Association in 1944, quoted the following statement made by the founder, Samuel B. Gross, in the year 1876: "It is safe to say that there is not a medical man on this continent who devotes himself exclusively to the practice of surgery and that American medical men are general practitioners and cover the entire field of medicine, surgery and obstetrics".

This was the state of affairs at the close of the Nineteenth Century, and the practice of the so-called general surgeon embraced what we know today as orthopaedic surgery. However, during the first quarter of the Twentieth Century came what Platt describes as "the abdominal revolution". The general surgeon developed this field with striking success and, with refinement of technique and diagnosis, he has performed surgical feats which formerly would have seemed impossible. Furthermore, with improvement in preoperative and postoperative care, he has extended the field of operation on the gastro-intestinal tract to the older age group and substandard risk patients, with a resultant declining mortality rate. With this emergence of abdominal surgery as a specialty, other special fields have ensued, until at the present time there are twelve divisions in what was formerly known as general surgery. This development has produced a violent reaction in the ranks of the irreconcilables among the older surgical practitioners, notably Bevan, who expressed himself in these words: "The scope of the field to be covered by the American Surgical Association has never, until comparatively recently, been a matter of question. Since the founding of the Association in 1880, it has always been the purpose of the organization to cover the entire field of surgery. What would become of general surgery if the head, spine, and peripheral nerves were lopped off by the neurosurgeons; if the specialists in thoracic surgery took over the chest; if the urologist took over the genito-urinary organs; proctologists, the rectum and colon; orthopaedic surgeons, fractures and dislocations and the extremities; and plastic and oral surgeons appropriated their own special field? The gynecologists and obstetricians have for a long time claimed the female genito-urinary tract as exclusively their own. This would leave to general surgery nothing except that small part of the body between the diaphragm and the umbilicus; and now comes another claimant into the field, the tumor specialist or the cancer specialist. I have no hesitation in denouncing this last as a very serious blunder. We might just as well develop specialists in inflammation of all parts of the body as to train men as specialists in cancer involving all parts of the body."

One point that we must always remember is that specialization has led to an increased amount of research; in fact, specialization many times implies special investigation and

we all acknowledge our indebtedness to research in its advancement of medical knowledge. But in the words of Daniel Fiske Jones, "specialization has robbed the general surgical service to such an extent that it really does not exist".

Nevertheless, some of the leaders in surgery today recognize and approve the evolutionary trend as, for example, Coller in the following statement: "True specialization is a striving for perfection and we owe a great debt to those who have by their efforts in limited fields so greatly enhanced our knowledge as a whole".

Wangensteen, too, in an article entitled, "The Surgeon and His Trust", sets forth some pertinent facts of great interest. He states: "There are still a few surgeons who affect to believe that they can take all of surgery for their province. They know as well as any one that their performance in such a wide category of operative procedures is substandard in some of these areas when judged in the critical light of what constitutes good practice. In our time we have seen the province of the general surgeon shrink so much that occasionally we wonder what areas of surgery are embraced in the designation general surgery. Yet this is as it should be. If a teacher of surgery were so ardent a student in his art that he wished to encompass the entire field, an aspiration more ambitious than praiseworthy, he would remain all of his days a learner and would thereby lose the important opportunity to give directional growth to a small sphere of surgery. Teachers of surgery must prove themselves in the next generation as well as in this. The teacher who leaves no intellectual progeny has not been fully alive to his responsibilities nor wholly faithful to his trust." Wangensteen concludes: "Let us be thankful that the day of the all-around surgical specialist is done! Surgery is not advanced by that type of activity, and no matter how talented the surgeon, he cannot do equally as good work in all these provinces.

"The background of training of the surgeon should be broad. But having acquired orientation and competence, a surgeon must of necessity, if he aspires to rise above mediocrity, give selective direction to his activity instead of trying to grow in all directions simultaneously."

For the purpose of securing data concerning the present status of orthopaedic surgery in our medical schools, I sent questionnaires to the heads of the orthopaedic departments. They all responded promptly, and I made an analysis of the information secured from fifty-three schools. Of these, seventeen have major departments of orthopaedic surgery,—that is, departments which have a certain measure of control over the amount and distribution of the budgets, appointments and promotions on their staffs, and representation on the executive advisory committees of the deans of their respective schools. Thirty-six are subdepartments in surgery, but of these, eleven have appointments on the deans' committees; that is, in approximately one-third of our medical schools the orthopaedic divisions have autonomy. Some of these major divisions, however, apparently are inadequately financed. In 70 per cent. of the schools, fractures, osteomyelitis, joint infections, and bone tumors are treated exclusively on the orthopaedic service. In the remaining schools, the treatment of these conditions is divided between orthopaedic surgery and general surgery, while in a very small percentage they are treated solely on the surgical service. In 20 per cent., amputations are cared for exclusively on the orthopaedic service; in 8 per cent., they are treated on the surgical service; and in 72 per cent., the treatment is divided between the two services. Acute surgery of tendons is performed on the orthopaedic service in 23 per cent. of the schools, on the surgical service in 34 per cent.; and in 43 per cent. it is divided between the two. Treatment of infections of the hand is assigned to the orthopaedic service in 16 per cent., to the surgical service in 22 per cent., and to both services in 62 per cent. Teaching of the subjects of fractures, osteomyelitis, joint infections, bone tumors, amputations, and surgery of the tendons and of the hand is divided between the two divisions of surgery in about the same proportion as the treatment of these conditions, with a slight margin indicated in the interest shown in these studies by the division of surgery.

The information received shows conclusively that the treatment of injuries, infections, and tumors of the bones and joints, which has been a matter of controversy between the two services, has finally become the province of the orthopaedic surgeon. The treatment of amputations is rather evenly divided; but, because of the importance of preventing deformity of the joints, a problem in all amputations, and of the need for the development of prostheses both temporary and permanent, so vital to the patient's best interest, I would venture to predict that all amputations will ultimately come under the supervision of orthopaedic surgeons.

The responses to the questionnaires show that a majority of the schools have separate divisions of neurosurgery, orthopaedic surgery, genito-urinary surgery, obstetrics, and gynecology; but, in some cases, they do not have special divisions of thoracic surgery, plastic surgery, vascular surgery, surgery of the hand, and proctology,—this is particularly true of the last two branches.

In about two-thirds of our medical schools, in addition to surgery of the abdomen and neck and the teaching of the fundamentals of surgery, the general surgeon still does some thoracic surgery, rectal surgery, common skin grafts, treatment of infections of the hand, and of vascular conditions, including treatment of varicose veins and ligations for thrombosis.

In 63 per cent., the orthopaedic surgeon teaches the fundamentals of surgery—such as wound healing, sepsis, trauma, shock, and hemorrhage—in relation to his own special field. The number of hours given to the teaching of orthopaedic surgery is agreed upon in a majority of the schools by the professor of orthopaedic surgery and the professor of surgery. In other schools, this decision is made by a special faculty committee or a regular committee on the curriculum. In about one-half of the schools, the teaching of orthopaedic surgery is a postgraduate subject. In approximately 40 per cent., the head of the department of orthopaedic surgery has some voice in the selection of interns; and in 48 per cent., he is consulted in the choice of assistant residents in surgery.

In answer to the question: "*Should The American Board of Orthopaedic Surgery decide to require an additional year of training in surgery as a requisite to formal training in orthopaedic surgery, do you believe that the department of surgery in your medical school will cooperate in the matter of providing assistant residencies in surgery?*"—there were thirty-two replies in the affirmative and six in the negative.

To the question: "*Would men desiring to train in orthopaedic surgery have equal opportunity to secure residencies in surgery with men desiring to train in general surgery?*"—out of a total of forty-three schools, thirty-one replied in the affirmative and twelve in the negative.

To the question: "*As a rule would preference be given to men desiring to train in general surgery?*"—out of thirty-nine schools, eighteen replied in the affirmative and twenty-one in the negative.

I am inclined to believe that some of these replies may be in the nature of personal impressions, rather than the result of reflection or careful inquiry.

Now that The American Board of Orthopaedic Surgery has announced officially that it will require an additional year of training in surgery, I consider it a matter of vital importance to determine immediately whether the medical schools will cooperate in providing the necessary residencies for students in orthopaedics on an equal footing with postgraduate students in other branches of surgery. I think we should insist upon this. After all, equality of opportunity is one of the cardinal principles of a democracy.

In reply to the question: "*Do you have facilities for complete training in orthopaedic surgery, including fractures, children's orthopaedic surgery, and fundamental sciences?*"—forty-one indicated that they had all the necessary facilities and ten were lacking in some particulars.

The question, "*Do your facilities for training in orthopaedic surgery include emergency*

surgery, enabling your residents to treat emergency cases in their own field and also to observe emergencies in other fields of surgery, such as head injuries, acute abdomens, etc.?"—brought forty-six affirmative replies and four negatives. The necessity for this experience is an integral part of the broad general training which I consider has not been sufficiently emphasized.

To the question: *"In the history of your school has the professor of surgery been selected from any field other than general surgery?"*—forty-one answers were in the negative and ten in the affirmative. Of these ten, there were six neurosurgeons, two thoracic surgeons, and one whose chief interest was vascular surgery. There was none among the number who bore the title of orthopaedic surgeon.

To the question: *"If you could participate on an equal basis with men in other special fields of surgery, including the so-called general surgery, in decisions as to teaching programs, distribution of funds for the budget and the general management of the surgical department, would you, in your opinion, serve the best interests of the patient as well as the student, and promote the advancement of orthopaedic surgery as the head of a subdepartment of surgery or the head of a completely independent department of orthopaedic surgery?"*—seventeen out of forty-nine stated that they would prefer to be heads of subdepartments and thirty-two preferred major status. In other words, the proportion is two to one in favor of making orthopaedic surgery a major division, on an equal footing with other divisions of surgery.

In this paper, I have endeavored to describe the progress of orthopaedic surgery from its embryonic stage in the latter part of the Nineteenth Century up to its present maturity. Today, we are fulfilling the destiny predicted in the definition of orthopaedics by that great leader, Sir Robert Jones. We are both physicians and surgeons whose ultimate purpose is to restore, by manipulation, operation, re-education, and rehabilitation maximum function of parts affected by injuries and diseases of the locomotor system. Orthopaedic surgery of today covers the field of general surgery of yesterday. The so-called general surgery is a remnant from the past, because, as we all know, in the course of the development of surgery as a whole, many branches have split from the parent stem. These changes in surgery parallel changes in other fields of endeavor and are a part of the natural process of evolution and the mutations of progress. Of these special branches which have been developed, orthopaedics represents the largest single abstraction from the general field of surgery. The breadth of its scope and the broad field that it covers in the anatomy of the human body entitle it to an equal place in surgical teaching with any other division of surgery. Yet, the departments of orthopaedic surgery in the majority of our medical schools are still classified as subdepartments, and they have not acquired the autonomy to which they are entitled.

In our modern medical schools, the expression "general surgery" is used to designate the group of surgeons who, in the past, were general surgeons, but who now confine their major activities to surgery of the abdomen and neck. The term "general surgeon" is a misnomer; and at the present time it would be an anachronism for any surgeon to claim to cover the entire field of surgery. The continued use of the term is harmful in a number of ways in the development of surgery in our medical schools. It conveys to the mind of the student the idea that he is being taught the science of surgery as applied to the entire body, which is entirely erroneous. Because of the undue emphasis which is placed on abdominal surgery, the student inevitably gets a false perspective. One of the harmful results of this system is that the undergraduate regards orthopaedic surgery as relatively unimportant and a subject to be considered for postgraduate work. The magic words "general surgery" undoubtedly influence the future of many undergraduate students, particularly those who wish to excel. This prevents orthopaedic surgery from getting a just proportion of the high-class men who are material for future leaders and teachers. Moreover, the title "general surgeon" conveys to the minds of the deans and members of the executive faculties of our medical schools the impression that all-round ability

in surgery is always to be found in the ranks of the *soi-disant* general surgeons. In the past this may have been true, but in these days the belief that the general surgeon possesses the automatic and inalienable right to acquire the chair of surgery is out of date. As Platt points out, he is now only one among many in his capacity to contribute to techniques and fundamental knowledge.

In discussing the surgical picture with Dr. John Saunders, Professor of Anatomy in the University of California Medical School, whose contributions are known to all of you and who has been an invaluable aid to me in the development of the teaching of orthopaedic surgery, he made the following excellent analysis of the situation: "If we believe that the so-called general surgeon is in reality a specialist in abdominal surgery, then his activities must be grouped with those of other specialties. This leaves behind an area of common interest,—an area which comprises the fundamental principles of surgery and its basic elements. All surgeons possess a common interest in this field, to which they all contribute and where they may serve as a mental stimulus to one another. Furthermore, it is here that the important liaisons with the basic sciences should be established. Therefore the term 'general surgery' still possesses utility, but only when applied to a field which is general to all surgeons."

My first recommendation for future development would be that orthopaedic surgery should secure full recognition in our medical schools as a major department of surgery, with its own budget, the right to select members of its staff, control promotions, and be responsible only to the dean and to the executive faculty. This is, however, a general statement, as existing conditions in each school should determine the course of action. Every division of orthopaedic surgery must stand on its own merits, but my own observation and many discussions with leaders in various branches of surgery, together with a study of the responses to the questionnaires which I have cited, lead me to believe that the departments of orthopaedic surgery in most of our medical schools deserve the status of major departments.

Granted we are given our place in the sun, what should be our future course of action? I believe that we should do everything possible to promote integration in our department of surgery. Integration with the authority of a major division in surgery is quite a different matter from working under the handicap of the status of a subdepartment with little or no final authority. And with the power of autonomy, we must integrate the teaching of surgery from the broadest possible angle, in order to enable the undergraduate to secure a correct perspective. I believe that we should assume an active role in the teaching of general principles of surgery as a whole, as well as their application to our particular field. As Carl Badgley, my former associate at the University of Michigan, so well expressed it—"Our aim should be first to train doctors, second to train surgeons, and then to train orthopaedic surgeons". This would give us an opportunity to disabuse the minds of students of prevailing misconceptions as to the limited scope of orthopaedics. We should no longer be the stepchild in surgery. In the teaching of postgraduates and for the enhancement of our own knowledge and breadth of outlook, we need intimate contact with men in other branches of surgery. Specialists in the same surgical field are not for long the best company for each other. The stimulating effect of close association with men in the other surgical divisions is indispensable to our future development. In our modern medical schools, surgical rounds should be, in a certain sense, a kind of forum where student, intern, resident, and visiting staff could see surgery in its true perspective and evaluate the contribution of each branch. These forums would be invaluable in solving our common problems, particularly in fields of surgery which overlap. For example, consider the untold benefits which would result from a combined study by the neurosurgeon and the orthopaedic surgeon of every phase of treatment in cases of suspected lesions of the intervertebral disc. And what good results would ensue from a combined study by the neurosurgeon, genito-urinary surgeon, and the orthopaedic surgeon of paralytic lesions arising

from injuries to the spinal cord! As my friend, Fred Coller, says: "What we should strive for is not to make everyone a general surgeon, but to make all who practice in any surgical field 'Generals in Surgery'", and Harry Platt, in the London *Lancet*, admirably sums up the goal we are seeking in these words: "If we aim at the highest standards for the future, we shall ensure that the orthopaedic surgeon will be among the best educated of the corps of consultants and specialists. It is the duty and responsibility of those entrusted with the training of the orthopaedic surgeon of the future to ensure that we recruit and educate as high a proportion of scholars and teachers as any other of the major specialisms in medicine and surgery. For in the world of medical science, as in society, we shall be ultimately judged by the quality of our contributions to the advancement of knowledge."

I would like to see the department of surgery in our medical schools organized in such a way that the professor of surgery would serve as executive head, with a responsible group of "cabinet officers", consisting of the chiefs of the major divisions in surgery. This group all would contribute to the teaching of fundamentals in the undergraduate schools, so that the students could obtain a true perspective on surgery as a whole. With methods of teaching agreed upon and duplication avoided, it would allow the student more time for practical observation. In addition, the undergraduate should be encouraged to take advantage of broad basic training in surgery before specializing in any particular field. Such a department of surgery would inevitably create an enthusiastic *esprit de corps*, and fine teamwork would be the natural outcome. It would be like a well organized football squad, with no individual stars or prima donnas to unbalance the combined effort of the entire team. This might ultimately develop into a working group similar to the highly successful club which Gallie has promoted in the University of Toronto. The selection of the professor of surgery should not be restricted to any particular field of surgery, but rather the appointment should be made on the basis of scholastic attainments, breadth of background, and demonstrated ability to get along with others. In addition, the head of the department of surgery should possess an unbiased attitude towards the development of all branches of surgery and a discriminating mind which would enable him to recognize exceptional ability in the younger men who are to be the leaders of the future; and, above all, he should have the skill to bridge the gap which too frequently exists between the abstract teaching of basic sciences and their clinical application in wards and laboratories.

These are the high ideals which we should strive to attain. We may not always succeed, but in the words of Robert Browning:

". . . a Man's reach should exceed his grasp,
Or what's a Heaven for?"

Before concluding this paper, I wish to express my deep appreciation to the members of this Association for the great honor they conferred upon me in naming me their President. It is a distinction which I value highly; and, if, during my term of office, I have contributed in some small measure to the recognition of the well-earned right of orthopaedic surgery to enjoy the status of a major department in our medical schools, I shall not have worked in vain.

NOTE: I wish to express my appreciation to Mr. and Mrs. Sidney Ehrman for the sincere interest they have shown in the development of the Department of Orthopaedic Surgery in the University of California Medical School, and to Mrs. Margot Egan, who has been so generous with her time and knowledge in the preparation of this address.

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ARTHRODESIS OF THE ELBOW

A PRELIMINARY REPORT OF A NEW OPERATION*

BY MOSES GELLMAN, M.D., BALTIMORE, MARYLAND

From the Kernan Hospital for Crippled Children, Baltimore

Although it is generally agreed that the indications for arthrodesis of the elbow are few, a rather imposing number of procedures for the purpose of fusing this joint have been described [1,3,6,7,8,9,10,11].

The object of this paper is not to discuss the merits of arthrodesis, as compared with excision [2,4,5] of the elbow, but to propose an additional method of fusion, which may be useful in certain cases, especially in tuberculosis, where the orthopaedic surgeon feels that the circumstances justify the employment of this form of treatment.

The procedure is not too formidable. It brings relatively uninvolved bone surfaces into intimate contact. The graft is easily and firmly anchored. Bone from other sources is not needed, and material for bone pegs or chips is readily available. The radiohumeral joint is not disturbed, which allows for the possible retention of rotation of the forearm. The elbow joint may be placed at any desired angle without additional operative modification.

DESCRIPTION OF THE OPERATION

An incision is made on the inner aspect of the elbow from five centimeters above to five centimeters below the tip of the medial epicondyle of the humerus. The ulnar nerve is isolated and is freed sufficiently to permit careful retraction from the operative field.

*Presented before the Orthopaedic Section of the Baltimore City Medical Society, Baltimore, Maryland, April 28, 1947.

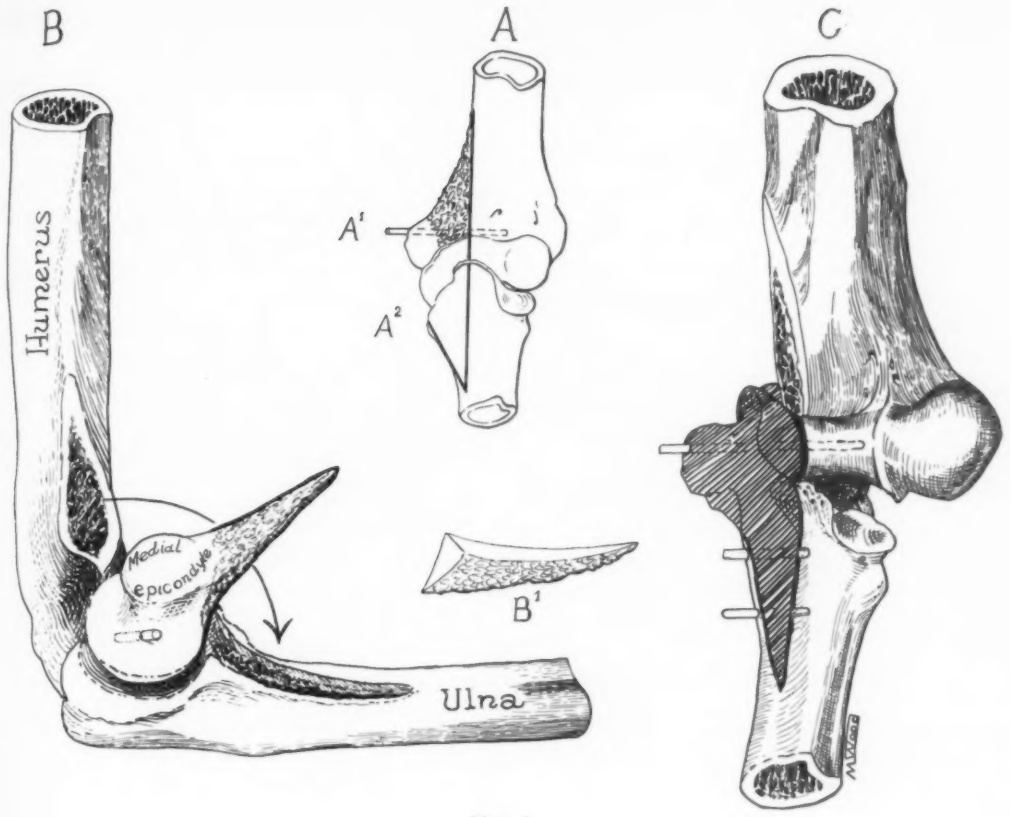

FIG. 1

All of the soft tissues (muscle attachments, periosteum, and capsule) are stripped from the anterior, medial, and posterior surfaces of the medial third of the lower portion of the humerus and from the medial and anterior surfaces of the upper end of the ulna. When this has been accomplished, the medial third of the anterior portion of the exposed humerus, as well as its medial margin, is roughened by the removal of a thin layer of cortical bone (Fig. 1,*A*).

Beginning at the top of the medial supracondylar ridge, approximately the medial third of the lower portion of the humerus is separated with an osteotome, flush with the humeral shaft, and parallel to its long axis (Fig. 1,*A*). When this piece has been freed, a wire, A^1, is passed transversely through the epicondyle and into the humerus to control this loosened mass of bone which will constitute the graft. This graft is then rotated downward until it lies upon the surface of the ulna; an outline of the graft is scratched on the surface of this bone, A^2. The triangular wedge outlined, B^1, is now removed from the anterior cortex of the ulna, and the humeral graft is again rotated downward and fitted snugly into the ulnar trough (Fig. 1,*B* and *C*).

After the most satisfactory angle for the elbow has been decided upon, two additional wires (or screws, or autogenous bone pegs made from the previously removed ulnar wedge) are inserted through the ulna and the transplanted bone to stabilize the graft (Fig. 1,*C*). The wire through the humerus may be removed and replaced by a screw or a bone peg. If it seems advisable, what remains of the triangular ulnar wedge may be converted into bone chips and packed into any crevice that appears to need them. If the ulnar nerve is under any tension, it is transposed anteriorly.

The soft tissues are allowed to fall back into position and are sutured securely, layer by layer. A plaster shoulder spica is applied, and is worn for eight weeks. When this cast

is changed, the protruding wires, if used, are removed. The cast is renewed at suitable intervals, until fusion of the elbow joint is demonstrated clinically and by roentgenogram.

CASE REPORT

W. S., a thirteen-year-old colored boy, was admitted to the Kernan Hospital on March 22, 1946, complaining of a swollen and painful right elbow, following injuries sustained in December 1945 and February 1946. The family history revealed that the patient's father had tuberculosis. The joint fluid was aspirated on several occasions. Smear, culture, and guinea-pig inoculation of the joint fluid were negative, but sinuses developed at the sites of the aspirations and remained open. The patch test was strongly positive for tuberculosis. In spite of immobilization by casts, the elbow remained swollen and thickened; the sinuses continued to discharge purulent material; and the roentgenograms demonstrated a progressive deterioration of the joint. Although as yet there were no laboratory evidences of tuberculosis, the entire clinical picture led to this diagnosis.

Accordingly, the described operation, which had been conceived several years before, was performed on May 17, 1946. When the first cast was removed on August 2, 1946, approximately twelve weeks from the date of operation, the elbow had fused. The wires were removed on September 13, 1946. During this procedure, the graft was found to be firmly united to the humerus and the ulna. Granulation tissue, curretted from the sinuses, was reported by the pathologist as tuberculous. The elbow has thus far remained solid, many months after removal of all support; this fusion is confirmed by the roentgenograms. An ulnar palsy, which followed the operation, has gradually cleared, but several sinuses are still draining.

NOTE: Since this paper was written, a similar condition seems to have developed in the opposite elbow. The biopsy report of sections from the glands of each axilla was "tuberculous adenitis".

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THE EFFECT OF ROENTGEN IRRADIATION ON EPIPHYSEAL GROWTH* †

II. Experimental Studies upon the Dog

BY JOHN A. REIDY, M.D., JAMES R. LINGLEY, M.D., EDWARD A. GALL, M.D., AND JOSEPH S. BARR, M.D., BOSTON, MASSACHUSETTS

From the Departments of Orthopaedic Surgery, Roentgenology, and Pathology and Bacteriology, Massachusetts General Hospital, Boston

Studies previously completed on the young rat [1,3] showed that it was possible to impede growth in the long bones by exposing the epiphyseal cartilages to roentgen-ray irradiation. These investigations demonstrated clearly that, with dosages of between 665 r and 1,165 r (roentgen units), the epiphyseal cartilage was affected profoundly. The adjacent tissues—such as synovial membrane, articular cartilage, cortical bone, bone marrow, and skin—evinced morphological changes of minor import.

To verify the results of the rat experiments and to expand the scope of the animal investigations, it seemed advisable to do a similar study on dogs. These experiments have been undertaken because of their possible therapeutic application to man.

TABLE I

Synopsis of the Experiment

Group	Amount of Irradiation	No. of Dog	Joints Treated	Period after Irradiation before Animal Was Sacrificed (*Months*)
A	800 r	5	Right knee and left wrist	7
		6	Right knee and left wrist	18
		11	Right knee and left wrist	24
		12	Right knee and left wrist	12
B	1,000 r	3	Right knee and left wrist	18
		4	Right knee and left wrist	12
		9	Right knee and left wrist	18
		10	Right knee and left wrist	7
C	1,200 r	1	Right knee and left elbow	12
		2	Right knee and left wrist	24
		7	Right knee and left wrist	24
		8	Right knee and left wrist	4

MATERIALS AND METHODS

Twelve puppies of both sexes were secured,—six from each of two litters of collie mongrels. They were approximately six weeks old at the time the roentgen treatment was given. They were maintained upon a nutritious diet, supplemented by cod-liver oil during the first six months. All were immunized against distemper. The animals were quartered in a large yard, with ample room for exercise. They were not restricted in any unusual manner during the course of the study.

* Read at the Annual Meeting of The American Academy of Orthopaedic Surgeons, Chicago, Illinois, January 29, 1947.

† Aided by a grant from The National Foundation for Infantile Paralysis, Inc., New York, N. Y.

The animals received roentgen irradiation* [1] through a 4-by-5-centimeter portal over the left foreleg at the radiocarpal joint, and over the right hind leg at the tibiofemoral joint. There was one exception to this plan of treatment. The left elbow of Dog No. 1 was treated instead of the left wrist. The portal covered the joint, the epiphyses, and the adjacent metaphyses. Dosages were given at a single sitting in equal amounts to one foreleg and one hind leg of each animal. One-half the dose was given through an anteroposterior portal and the other half through a postero-anterior portal. The dogs were divided into three groups (A, B, and C) of four each (two from each litter). Group A received 800 r; Group B, 1,000 r; and Group C, 1,200 r. The animals were sacrificed at intervals varying between four and twenty-four months, as shown in Table I.

FIG. 1-A

FIG. 1-B

Fig. 1-A: Photograph of Dog No. 9, showing shortening of treated left fore limb.
Fig. 1-B: Photograph of Dog No. 3, showing shortening and bowing of treated left fore limb. This animal showed the greatest deformity of any of the dogs.

Seven weeks after treatment had been given, small metallic markers were inserted into the diaphysis of each tibia and radius, at approximately the mid-shaft. This made it possible to determine by roentgenography the proportion of growth contributed by the distal and by the proximal epiphyses of these bones.

Teleoroentgenograms were made at the outset of the experiment and were repeated at intervals of approximately six weeks through the fortieth week, when the epiphyses were found to be fused and growth was essentially at a standstill. Thereafter, roentgenograms were made at various intervals, the final one just prior to sacrifice of each animal.

At the time of sacrifice, gross examination of both the treated and untreated members was carried out. Particular attention was directed to the tissues subjected to irradiation, and to their counterparts. Sections of skin, muscle, and other soft tissues, and of metaphyses, epiphyses, and articular surfaces of the lower portion of the radius, ulna, and femur, of the upper portion of the tibia, and of the patella and the carpal bones were taken from both sides for microscopic examination.

All tissues were fixed in 10 per cent. formalin. The bones, after fixation, were decalcified in a 5 per cent. aqueous solution of nitric acid. Sections were cut in colloidin and stained with hematoxylin and eosin.

* The source of irradiation was a roentgen-ray machine with the following factors: 200 kilovolt peak, 20 milliamperes, 50 centimeters target-skin distance, filtration of 0.5 millimeter of copper and 1.0 millimeter of aluminum. The half-value layer was 1.0 millimeter of copper. The rate of delivery was 38.5 r per minute.

TABLE II

TOTAL GROWTH OF TIBIA AND PERCENTAGE OF RETARDATION CAUSED BY TREATMENT

Group	Amount of Irradiation	No. of Dog	Length of Tibia			Retardation (*Per Cent.*)
			Untreated (*Centimeters*)	Treated (*Centimeters*)	Difference (*Centimeters*)	
A	800 r	5	10.8	9.0	1.8	17
		6	11.2	9.5	1.7	15
		11	9.4	8.5	0.9	10
		12	6.6	5.3	1.3	20
B	1,000 r	3	10.4	8.4	2.0	19
		4	12.2	10.3	1.9	16
		9	10.5	8.3	2.2	21
		10	9.9	7.8	2.1	21
C	1,200 r	1	10.8	8.6	2.2	21
		2	10.2	7.4	2.8	28
		7	9.2	7.2	2.0	22
		8	7.8	5.9	1.9	24

OBSERVATIONS

During the experiment the dogs were frolicsome, ate well, and suffered no illnesses of significance. At the conclusion of the study, they seemed entirely normal except for unilateral shortening of limbs, mild bowing of the fore limb in eight animals, and the local coarsening and discoloration of hair. The weight and torso size of the dogs appeared to be unaffected by treatment.

All of the dogs showed retardation of longitudinal growth of the treated extremities

TABLE III

TOTAL GROWTH OF RADIUS AND PERCENTAGE OF RETARDATION CAUSED BY TREATMENT

Group	Amount of Irradiation	No. of Dog	Length of Radius			Retardation (*Per Cent.*)
			Untreated (*Centimeters*)	Treated (*Centimeters*)	Difference (*Centimeters*)	
A	800 r	5	10.3	7.8	2.5	24
		6	11.0	8.6	2.4	22
		11	8.8	6.1	2.7	31
		12	6.3	4.1	2.2	35
B	1,000 r	3	9.9	6.3	3.6	36
		4	11.7	8.6	3.1	26
		9	9.5	5.3	4.2	44
		10	8.9	5.7	3.2	36
C	1,200 r	1	10.4*	8.1	2.3	22
		2	9.8	5.4	4.4	47
		7	8.9	6.2	2.7	30
		8	7.0	4.1	2.9	41

* The proximal epiphysis of the radius (elbow joint) was irradiated in this animal.

(Fig. 1-A). After irradiation, the difference in length between the treated and untreated limbs progressed for about six months, at which time growth of the extremities ceased. Thereafter the asymmetry remained stationary.

Eight animals showed mild bowing of the radius and ulna on the treated side (Fig. 1-B). This occurred in all three groups. No bowing of the hind leg was evident.

The hair in the treated areas became coarse, dry, and occasionally discolored. In a few instances local epilation occurred, but later the coat was restored.

The treated limbs appeared rather sensitive during cold weather. Although this was common to all the animals, it varied considerably in degree.

In some, the paws appeared to be acutely tender during the first few weeks after treatment, but later the hyperaesthesia subsided.

At the time of sacrifice, the only external findings were (1) shortening of the treated leg in all animals, (2) bowing of the treated fore limb in eight animals, and (3) discoloration and thinning of the coat of hair over the treated area in some dogs. Inspection disclosed a striking difference in the size of the treated joint when compared with the untreated joint,—the diameter was approximately one third smaller on the treated side. The periarticular structures were normal. The articular surfaces of the joints were smooth and glistening, with no evidence of cartilaginous or bony deformity.

In order to test the strength of the treated bone, both radii from one of the dogs in Group C (Dog No. 8), sacrificed before epiphyseal union had occurred, were dissected free of investing tissues. A measured shearing force was applied to the distal epiphyses, and separation from the shaft occurred at the epiphyseal plate when a force of forty pounds was exerted. The same force was necessary in both treated and untreated limbs. A similar experiment was carried out on a dog in Group A after the epiphyses had fused. In neither extremity was fracture caused by a force of eighty-eight pounds.

ROENTGENOGRAPHIC OBSERVATIONS

From the teleoroentgenograms which were made at regular intervals, it was possible to measure the total length of the tibia, radius, and ulna, and to determine the amount and percentage of retardation of growth which occurred as the result of the irradiation.

TABLE IV

TOTAL GROWTH OF ULNA AND PERCENTAGE OF RETARDATION CAUSED BY TREATMENT

Group	Amount of Irradiation	No. of Dog	Length of Ulna			Retardation (*Per Cent.*)
			Untreated (*Centimeters*)	Treated (*Centimeters*)	Difference (*Centimeters*)	
A	800 r	5	12.7	9.8	2.9	23
		6	13.4	11.0	2.4	18
		11	10.5	7.1	3.4	32
		12	8.1	5.6	2.5	31
B	1,000 r	3	12.3	8.4	3.9	32
		4	14.3	11.3	3.0	21
		9	11.8	6.5	5.3	45
		10	11.2	7.4	3.8	34
C	1,200 r	1	12.7*	10.0	2.7	22
		2	12.0	6.1	5.9	49
		7	10.9	8.6	2.3	21
		8	8.9	4.9	4.0	45

* The proximal epiphysis of the ulna (elbow joint) was irradiated in this animal.

TABLE V

AVERAGE RETARDATION OF GROWTH OF THE TREATED LONG BONE

Group	Amount of Irradiation	Tibia (*Per Cent.*)	Radius (*Per Cent.*)	Ulna (*Per Cent.*)
A	800 r	15	28	26
B	1,000 r	19	35	33
C	1,200 r	24	35	34
Average of whole series		19.3	32.6	31

FIG. 2-A

FIG. 2-B

Roentgenograms of Dog No. 7, two years after irradiation, show shortening of treated long bones.

TABLE VI

GROWTH FROM PROXIMAL AND DISTAL EPIPHYSES OF THE UNTREATED TIBIA AND RADIUS

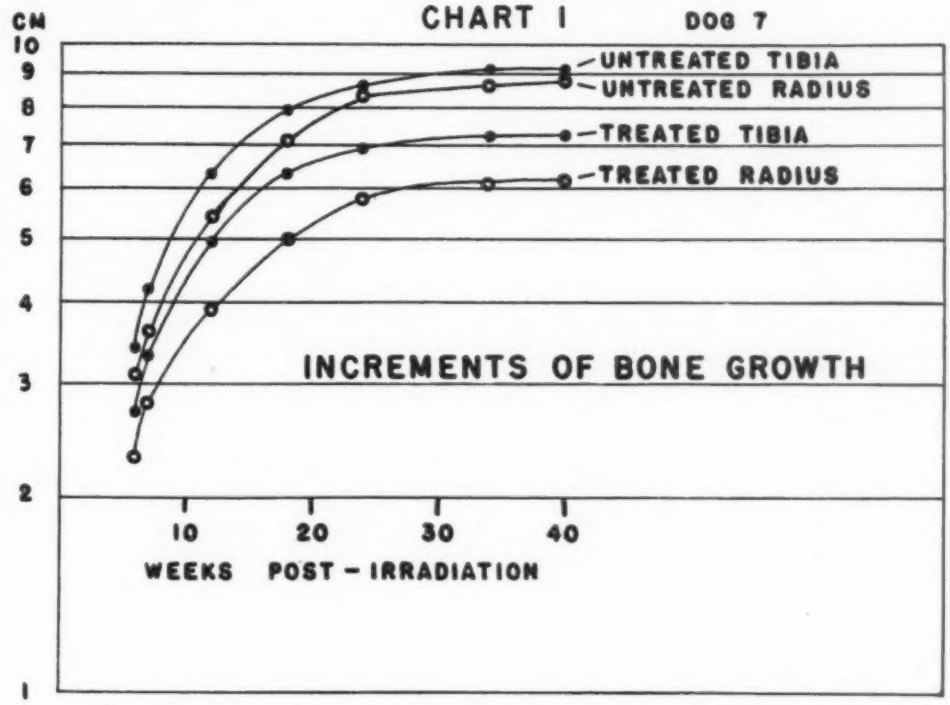
Group	No. of Dog	Tibia				Radius			
		Proximal Epiphysis (*Centimeters*)	(*Per Cent.*)	Distal Epiphysis (*Centimeters*)	(*Per Cent.*)	Proximal Epiphysis (*Centimeters*)	(*Per Cent.*)	Distal Epiphysis (*Centimeters*)	(*Per Cent.*)
A	5	2.9	51	2.8	49	1.9	35	3.6	65
A	6	3.2	52	3.0	48	2.2	34	4.2	66
A	11	2.7	49	2.8	51	1.8	33	3.6	67
A	12	1.8	51	1.7	49	1.2	34	2.3	66
Averages			51		49		34		66
B	3	2.5	50	2.5	50	1.6	30	3.7	70
B	4	3.4	51	3.3	49	2.2	35	4.1	65
B	9	3.2	52	3.0	48	2.0	36	3.6	64
B	10	2.9	49	3.0	51	1.7	33	3.5	67
Averages			51		49		34		67
C	1	2.8	52	2.6	48	1.9	35	3.6	65
C	2	2.7	52	2.5	48	1.8	33	3.6	67
C	7	2.8	52	2.6	48	1.9	36	3.4	64
C	8	1.8	49	1.9	51	1.6	41	2.3	59
Averages			51		49		36		64

FIG. 2-C

FIG. 3

Fig. 2-C: Roentgenogram of same wrist as in Fig. 2-A, two years after treatment. The contour of the ulna is normal.

Fig. 3: Roentgenogram of Dog No. 2 demonstrates bony resorption in the ulnar metaphysis, twelve weeks after treatment.



Growth retardation was noted in all of the bones treated (Figs. 2-A and 2-B), but the amount and the percentage of retardation varied considerably even within a given dosage group (Tables II, III, and IV). Over-all trends were apparent. When the percentages of retardation of growth of the long bones in each group were averaged, it became evident that 800 r produced less retardation of growth than 1,000 r (Table V). There was, however, little difference between the effect of 1,000 r and 1,200 r on the radius and ulna.

The range of impedance was wide, but there was close correlation between the mean and the average. In the tibia, the mean impedance was 20 per cent. and the average was 19.3 per cent. In the radius, the mean was 31 per cent. and the average was 32.6 per cent. In the ulna, the mean was 31 per cent. and the average was 31 per cent. The longitudinal growth of the tibiae and radii of Dog No. 7 is plotted on Chart I. The rate of growth was slowest in the treated radius.

The amount of growth contributed by both epiphyses of each tibia and each radius was computed by measurement from the metallic markers which had been placed in the mid-shaft of each long bone (Table VI). In the untreated tibia, longitudinal growth was nearly equal from the proximal and distal epiphyses. In the untreated radius, however,

TABLE VII

EFFECT OF IRRADIATION ON GROWTH OF PROXIMAL PORTION OF TIBIA AND DISTAL PORTION OF RADIUS

Group	Amount of Irradiation	No. of Dog	Growth of Proximal Portion of Tibia				Growth of Distal Portion of Radius			
			Untreated (*Centimeters*)	Treated (*Centimeters*)	Difference (*Centimeters*)	Retarded (*Per Cent.*)	Untreated (*Centimeters*)	Treated (*Centimeters*)	Difference (*Centimeters*)	Retarded (*Per Cent.*)
A	800 r	5	2.9	1.4	1.5	52	3.6	1.8	1.8	50
		6	3.2	1.9	1.3	41	4.2	2.3	1.9	45
		11	2.7	1.7	1.0	37	3.6	1.4	2.2	61
		12	1.8	1.0	0.8	44	2.3	0.9	1.4	61
Averages			2.7	1.5	1.2	44	3.4	1.6	1.8	53
B	1,000 r	3	2.5	1.4	1.1	44	3.7	1.1	2.6	70
		4	3.4	1.7	1.7	50	4.1	2.0	2.1	51
		9	3.2	1.2	2.0	63	3.6	1.0	2.6	72
		10	2.9	1.2	1.7	59	3.5	1.1	2.4	69
Averages			3.0	1.4	1.6	54	3.7	1.3	2.4	65
C	1,200 r	1	2.8	0.8	2.0	71	1.9*	0.3*	1.6*	84*
		2	2.7	0.5	2.2	81	3.6	0.5	3.1	86
		7	2.8	1.0	1.8	64	3.4	1.3	2.1	62
		8	1.8	0.8	1.0	55	2.3	0.6	1.7	74
Averages			2.5	0.8	1.7	68	3.1	0.8	2.3	74

* The proximal radial epiphysis of this dog was treated.

TABLE VIII

AVERAGE RETARDATION OF GROWTH FROM THE TREATED EPIPHYSIS

Group	Amount of Irradiation	Tibia (*Per Cent.*)	Radius (*Per Cent.*)
A	800 r	44	53
B	1,000 r	54	65
C	1,200 r	68	74

two-thirds of the growth resulted from the distal epiphysis and only one-third from the proximal epiphysis. It would be rational to expect, therefore, that the inhibiting effect on growth would be proportionately greater in a radius treated over the distal epiphysis than in a tibia treated over either epiphysis. This is shown to be true by the results listed in Table V. The effect of irradiation on growth of the treated epiphyses is shown in Table VII. The average retardation in the proximal epiphysis of the tibia is 44 per cent. with 800 r, 54 per cent. with 1,000 r, and 68 per cent. with 1,200 r. The distal portion of the radius was retarded 53 per cent. with 800 r, 65 per cent. with 1,000 r, and 74 per cent. with 1,200 r (Table VIII).

One unexpected and interesting observation was that the treated bone was not so short as might have been predicted on the basis of the known amount of retardation of growth of the treated epiphysis. This was caused by the increased rate of growth in the untreated epiphysis of the treated bone (Table IX). In twenty of the twenty-two pairs of limbs, the growth from the untreated epiphyses in the treated limbs exceeded that resulting from their counterparts in the untreated limbs (Charts II and III).

There was a decrease of about 20 per cent. in the diameters of the treated joints, as

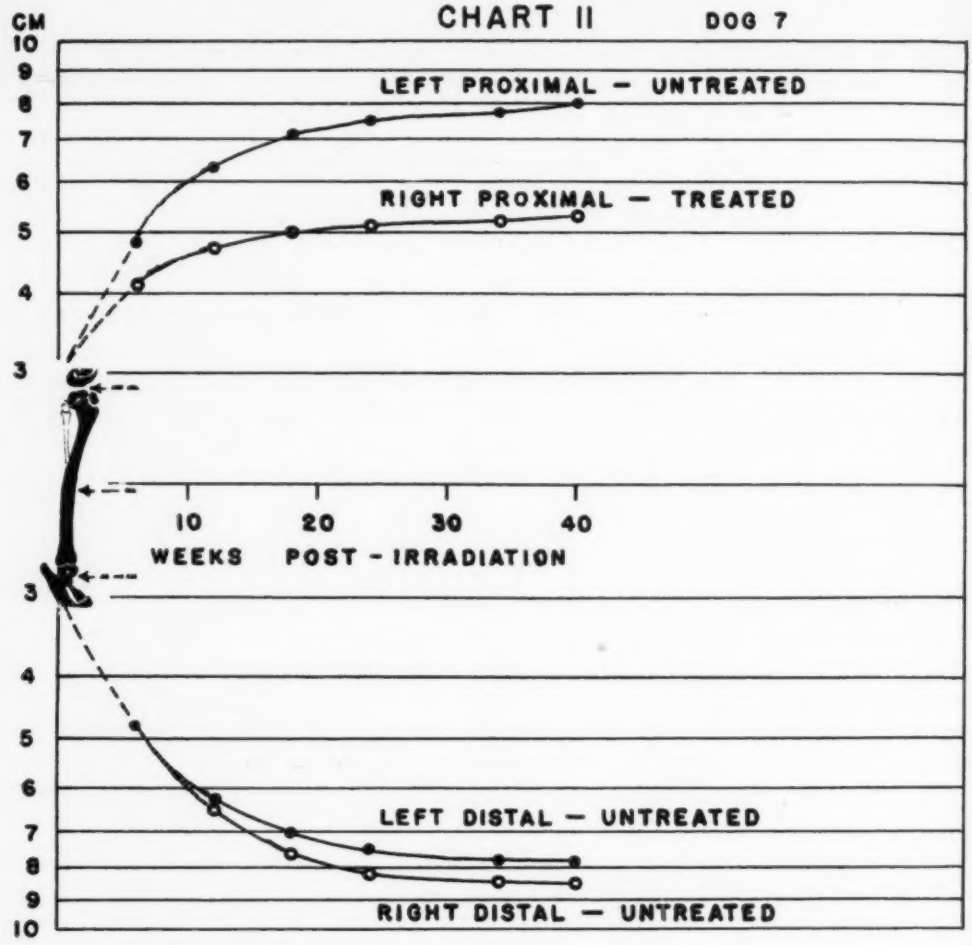
TABLE IX

EFFECT OF IRRADIATION ON THE UNTREATED EPIPHYSIS OF A TREATED BONE

No. of Dog	Growth of Distal Portion of Tibia		Growth of Proximal Portion of Radius	
	Untreated (*Millimeters*)	Treated (*Millimeters*)	Untreated (*Millimeters*)	Treated (*Millimeters*)
5	28	34	19	20
6	30	35	22	24
11	28	34	18	19
12	17	19	12	12
3	25	31	16	20
4	33	42	22	28
9	30	37	20	16
10	30	34	17	20
1	26	31		*
2	25	27	18	19
7	26	32	19	22
Averages	27 (15.6%)	32	18 (10%)	20

* In this dog the proximal radial epiphysis was treated. The distal radial epiphysis on the treated side showed increased growth of 11 per cent.

NOTE: Dog No. 8 is not included in this table, as the animal was sacrificed before growth had been completed.



GROWTH OF TIBIAL EPIPHYSES (CM)

compared with the untreated ones. The diameters of the shafts of the bones were diminished approximately 10 per cent.

Roentgenographic evidence in the twelve dogs, including those which had active use of their extremities for the full two years, showed no bone or joint deformity other than a mild bowing which occurred in eight of the treated fore limbs. The joint surfaces were smooth, and the joint spaces were preserved. There were no detectable arthritic changes.

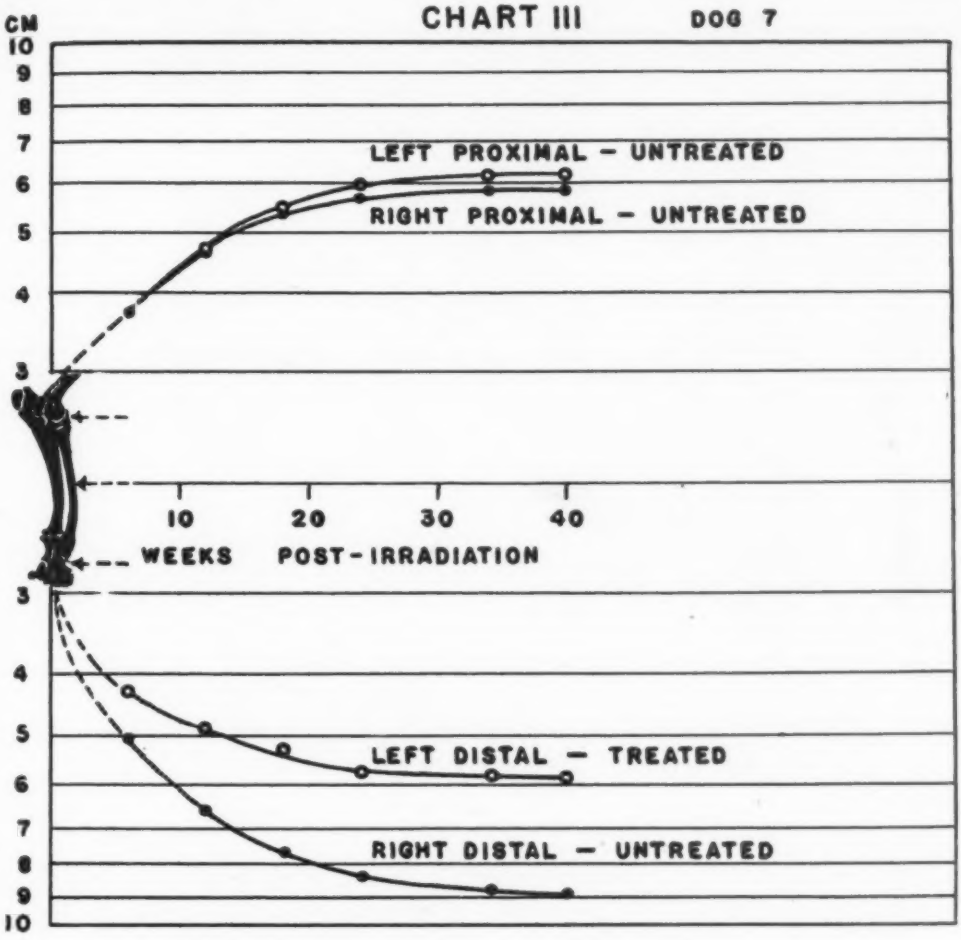
In three animals (two in Group A and one in Group B), roentgenographic evidence of temporary bone resorption in the metaphysis of the treated ulna was found (Fig. 3). This reached its maximum between twelve and eighteen weeks. Healing with remineralization occurred spontaneously (Fig. 2-C). One dog in Group B and one in Group C showed a minor osteolytic focus in the region of the tibial tuberosity at about eighteen weeks, but this had healed in twenty-four weeks.

In summary, the roentgenographic studies have brought out the following points:

1. Marked retardation of longitudinal growth was produced by dosages of roentgen rays ranging from 800 r to 1,200 r, and the retardation was roughly proportional to the x-ray dosages.

2. Minor localized osteolytic or resorptive phenomena which occurred in treated bones were transient, and healed completely.

3. The radius and ulna, treated over their distal epiphyses, showed considerably



GROWTH OF RADIAL EPIPHYSES (CM)

more shortening than the tibia, treated over the proximal epiphysis. This was probably due to the fact that the distal epiphysis of the foreleg normally contributes two-thirds of the growth increment, whereas the proximal tibial epiphysis normally contributes only one-half.

4. The epiphysis at the untreated end of a treated bone contributes more to the length of the shaft than the corresponding epiphysis in the untreated side. No satisfactory explanation of this stimulation of growth is apparent.

HISTOLOGICAL OBSERVATIONS

Since only one dog in each of the three groups was sacrificed prior to epiphyseal union, only three animals could be studied histologically for the effects of irradiation upon growing epiphyseal cartilage. In these three animals, the treated epiphyses showed severe changes, similar to those described previously in the rat [1, 3, 4]. The treated epiphyseal cartilage showed evidence of very severe damage, and the growth process was practically at a standstill (Figs. 4 and 5). The matrix was palely stained, mottled, and of irregular thickness. Primitive chondrocytes were diminished in number, separated widely, and frequently gathered into clusters without polarity. The columnar arrangement persisted, but in very abnormal fashion. The columns, although arranged in longitudinal fashion, showed deviation in course, and were often grouped together with sparsely cellu-

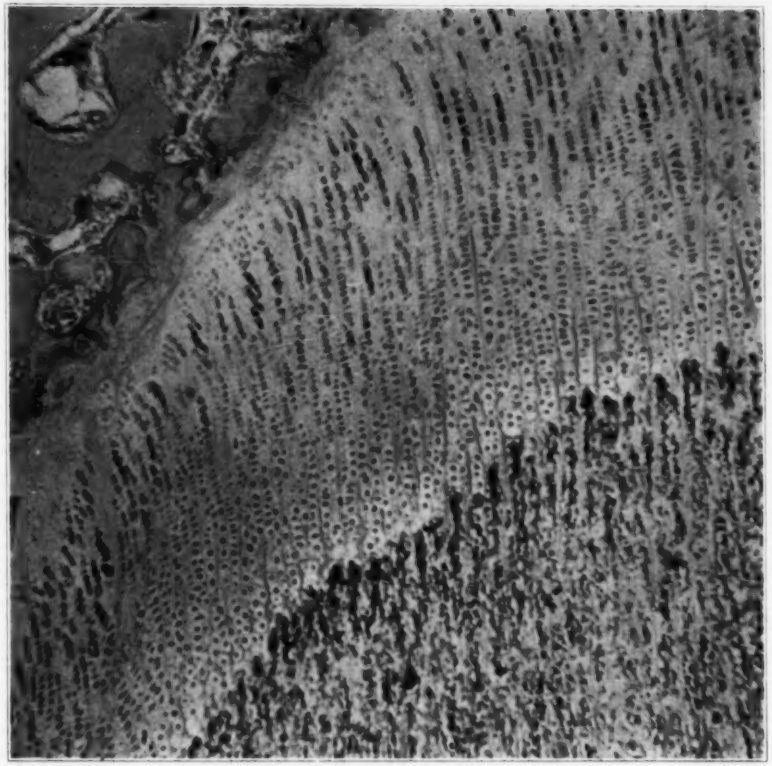


FIG. 4

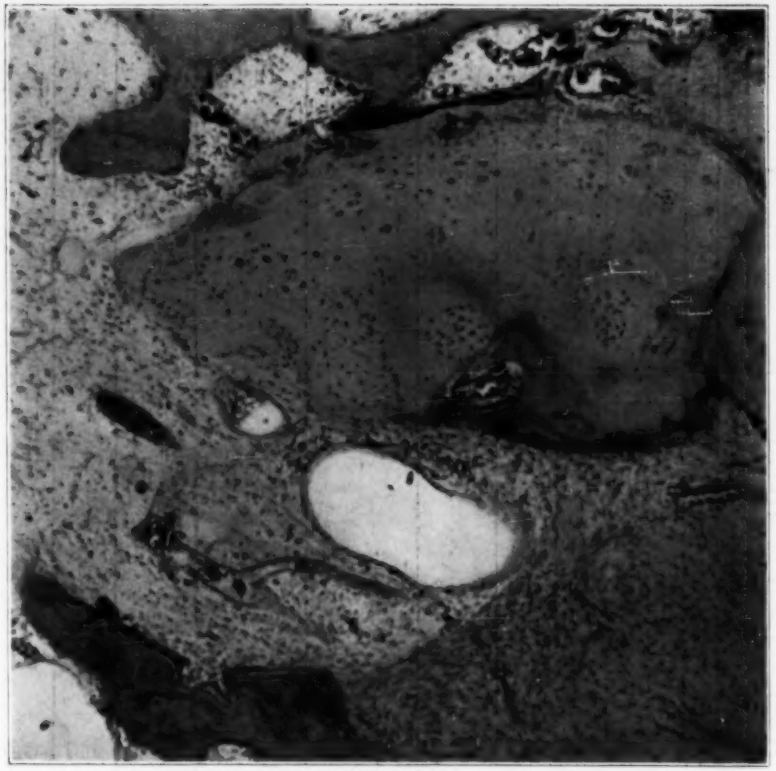


FIG. 5

Fig. 4: Showing regular, elongated, narrow columns of active chondrocytes with uniform mineralization at their metaphyseal ends. Included is a segment of the epiphyseal bone plate, containing fatty marrow (× 90).

Fig. 5: The cartilage is pale, mottled, and uneven, and the columnar arrangement has been lost. Marrow in both epiphysis and metaphysis is fibrous in character. An irregular plate of bone lies horizontally across the metaphyseal margin. Capillaries may be noted, penetrating the degenerated cartilage (× 90).

FIG. 6-A

FIG. 6-B

Fig. 6-A: Section of articular surface of the untreated patella in Dog No. 3 (aged one and one-half years). There is a relatively smooth "cement line" between cartilage and underlying bone. The articular surface is sharp, the columns of chondrocytes regular, and the matrix staining character normal. The normal thickness of the cartilage is apparent (× 90).

Fig. 6-B: Articular cartilage of treated patella from Dog No. 3 (1,000 r). The surface remains smooth and the cartilage is thinned, chondrocyte columns are irregular, and the cement line is "scalloped" (× 90).

lar, fibrillar matrix intervening. The chondrocytes showed degenerative features, varying from swelling to pyknosis and fragmentation. No inflammatory exudate intruded. Penetrating the cartilage plate were occasional capillary channels. There were many widely distributed foci of calcification, dissociated from the normal metaphyseal location. Frequently eosinophilic stripes of partial mineralization extended through the plate, from the bony epiphysis to the metaphyseal marrow. In the zone of new-bone formation, the parallel fragile spicules of calcified cartilage, present in the controls, were replaced by broad, generally horizontally disposed, bony trabeculae, giving clear-cut evidence of cessation of growth. The subepiphyseal marrow contained oedematous, fibrous tissue which was focally myxomatous and lacking in hematopoietic cells. These cells appeared in undiminished numbers and normal proportions in the marrow cavity of the diaphysis. Cortical bone was unaffected. Even those cancellous trabeculae in the subepiphyseal zone of sclerosis exhibited normal intrinsic structure.

There were no stigmata of the extensive degenerative process, just described, in any of the dogs sacrificed after epiphyseal fusion had been completed. In one, a thin horizontal line of cancellous bone marked the site of the resorbed cartilage, but this was also present on the untreated side (Fig. 9). The microscopic appearances of the marrow and cortex were identical bilaterally. Fatty marrow continued uninterruptedly from shaft into epiphysis with no residue of degeneration, fibrosis, or evidence of abnormal hematopoiesis.

Particular attention was directed to the joints and their contiguous surfaces. These included the patella, the femoral condyles, the upper tibia and attached fibrocartilage, the lower end of the radius, and the carpal bones. Despite some variation in degree, similar changes were noted in all. These were, in the main, degenerative in character; and their presence contrasted strikingly with the inconsequential findings which had been observed during the previous studies on rats.

Without exception, in the present study, all articular cartilages which had been subjected to irradiation showed microscopic evidence of degenerative changes, which increased in severity in direct proportion to the time intervening between treatment and sacrifice. In only one instance could they be considered more than slight to moderate in extent.

One relatively constant observation was the thinness of the treated articular cartilages. In three-fourths of the comparisons, made by actual measurement, the irradiated articular cartilage was only one-half to three-fourths of the thickness of the control joint from the opposite limb. This finding was sufficiently frequent to exclude the possibility of variation in the sectioning angle as a cause, and in no instance was the control cartilage found to be thinner (Figs. 6-A and 6-B). In view of the fact that the treated joint was smaller and the treated bone was shorter than the normal one, it would be surprising if the treated articular cartilage were as thick as that of the control joint. It is probable that the apparent narrowing of the articular cartilage was entirely in keeping with the size of the joint itself.

There was slight variation in the hyaline matrix, and pallor of staining. That the texture of the cartilage was poor was attested by the fraying of the surface, noted in some of the sections. This was not believed to have occurred during life, but was nonetheless considered of some significance. In a few instances (five joints), superficial erosion was present. Cleft formation was rarely seen. In one joint (the radiocarpal joint in Dog No. 7) there was complete, obviously pathological denudation of all cartilage, with exposure of the underlying bone. This was so different from the appearance of any of the other joints that it was considered to be due to undetected trauma. In all other instances the surfaces of the joint cartilage were smooth and adequate for normal function.

The abnormalities of the joint cartilage were minor in degree, and of little functional import. They were recognized only by microscopic study. The cartilage cells in all treated cartilages, however, were abnormal in one respect or another. The changes consisted in loss of polarity and consequent disarrangement of the normal longitudinal

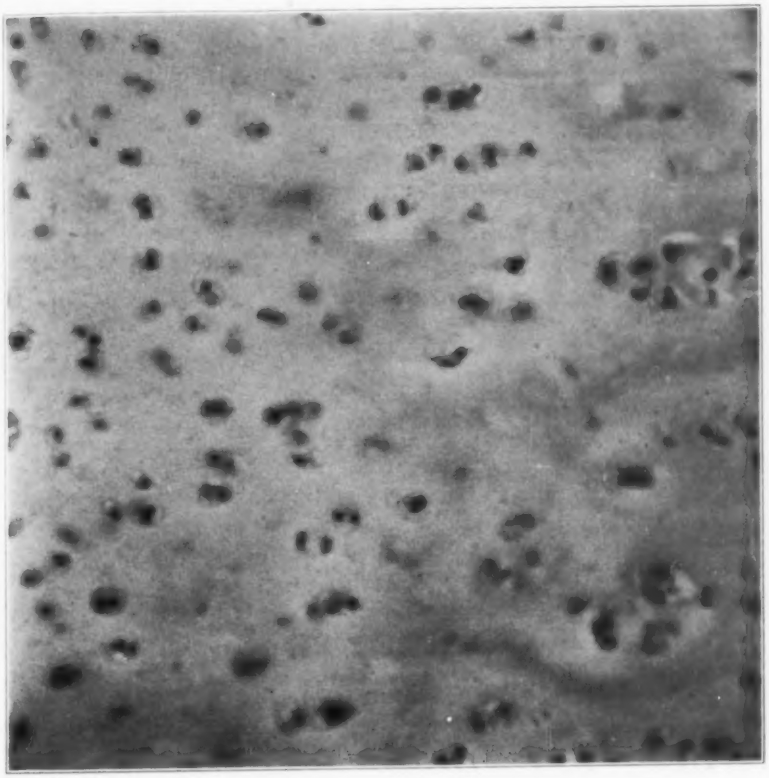


FIG. 7-B

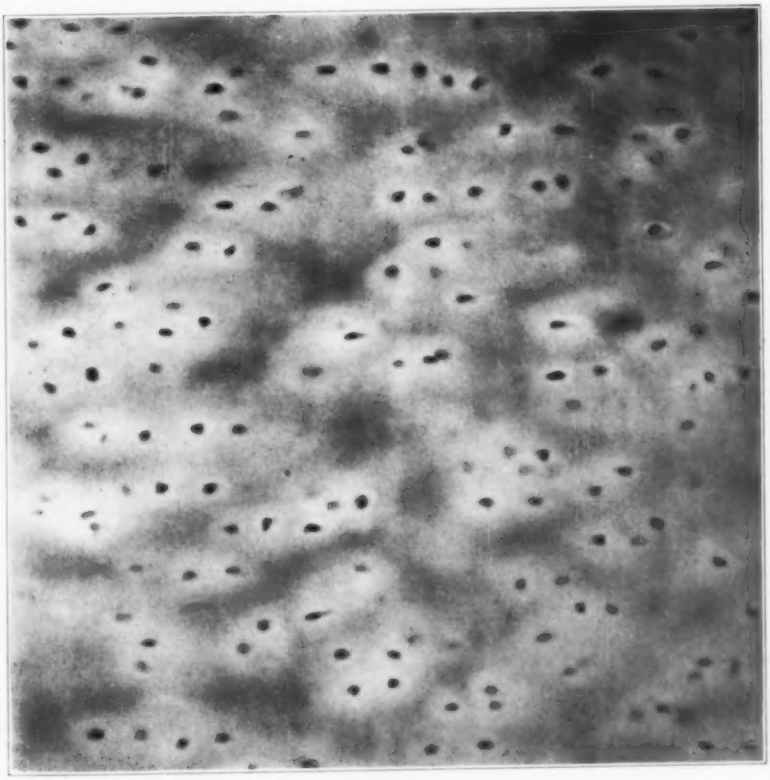


FIG. 7-A

Fig. 7-A: Articular cartilage of untreated patella from Dog No. 4 (aged one year), showing regularity of cartilage-cell arrangement and staining quality. Chondrocytes are small, and their nuclei are single and relatively uniform in size (× 225).
Fig. 7-B: Treated patellar cartilage from Dog No. 4 (1,000 r). Cartilage cells are irregular in size and distribution. Many contain two or more nuclei with varied staining quality, and there are frequently cluster-like aggregations. The staining character of the cartilage matrix is also obviously abnormal (× 225).

FIG. 8-A

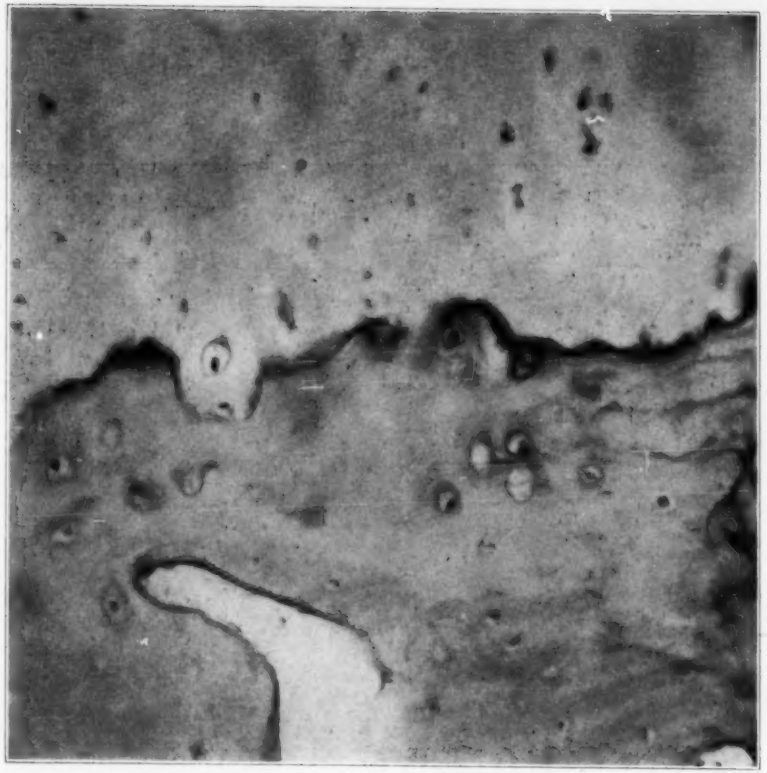


FIG. 8-B

Fig. 8-A: The patellar cement line in the untreated hind limb of Dog No. 7 (aged two years). Cartilage is similar in appearance to that shown in Fig. 6-A. The sharp, relatively smooth line of division between cartilage and subjacent bone is well shown (× 225).

Fig. 8-B: The cement line in the contralateral treated patella (1,200 r) of Dog No. 7. Scalloping is demonstrated, and the degenerative changes in the articular cartilage are readily appreciated (× 225).

FIG. 9

FIG. 10

Fig. 9: Tibia from the treated limb of Dog No. 4 (aged one year). Normal contours persist. The line of epiphyseal fusion is shown by the horizontal dense zone of cancellous bone. This is identical in appearance to the contralateral untreated limb (× 9).

Fig. 10: Articular surface of lower end of radius in Dog No. 7 (aged two years), treated with 1,200 r. There is denudation of cartilage and eburnation of the exposed bone. Trabeculae are coarse, and the marrow spaces which extend directly to the cartilage-free surface are fibrous in content (× 225).

columnar structure (Figs. 7-A and 7-B). There was swelling of lacunae, with or without concomitant abnormalities of the enclosed chondrocytes. The latter varied from cells with normal structure to those with either pyknosis or cytolysis. Frequently, reduplication caused the development of cluster-like aggregations. Changes of this nature were more pronounced in the deep portions of the cartilage, in the vicinity of the subchondral bone; and in two instances small crevice-like cysts were found at the chondro-osseous juncture. In general, there was diminished cellularity, becoming more pronounced as the surface was approached.

Normally in the cement zone, the area in which the articular cartilage and subjacent bone are joined, there is deep basophilia of both bone and cartilage for a short distance; and the line of division is abrupt, sharp, and relatively straight (Fig. 8-A). In treated joints there was considerable variation in the depth of basophilia, and the cement line was irregular and quite strikingly scalloped in appearance (Fig. 8-B). The scalloping was present to a significant degree in almost all treated bones, and probably represented evidence of some change in matrix consistency or mineralization.

Except for this, the subchondral structure was essentially normal. In the single joint in which denudation occurred (radiocarpal joint of Dog No. 7), there was true eburnation, but no other evidence of sclerosis or thickening (Fig. 10). In one case a minute osteophyte had formed at the margin, near the point of capsular insertion. Occasionally a small cluster of trapped chondrocytes was found in the plate, but this also occurred on occasion in the controls. Epiphyseal marrow substance was fatty, and the cancellous structure was normal.

Portions of synovial membrane and capsule were examined in all joints. The capsule was perfectly normal in all except the single instance noted (Dog No. 7). Here there was oedema and a rather marked round-cell infiltration. The synovial membrane was, as a rule, essentially normal. A few minor lesions were found, but these obviously were not primary in nature. In two instances a minute tongue of synovial membrane was affixed to the marginal cartilage in a "creeping" fashion, but no erosive qualities were manifest. In one section, small fibrinoid deposits appeared in several otherwise normal synovial fronds, and in three, fibrinoid flakes were lying free in the cul-de-sac. In one joint there was a tiny loose body, cartilaginous in nature, free in the joint space. Occasionally epithelial-like palisading of the superficial synovial layer was seen,—a feature which could not be considered abnormal, since it occurred also in the untreated joints. One synovial section showed a marked papillary structure without associated inflammation. Two other joints contained a scant sprinkling of lymphocytes and plasma cells.

Sections of skin overlying the epiphyses were also subjected to scrutiny. As noted in the gross examination, the hair shafts appeared coarser; and, in some, depigmentation was noted as well. Nevertheless, histologically, no striking abnormality was evident in any section. Keratosis was normal in amount, and there was no follicular plugging. The corium and subcutaneous tissue showed no fibrosis, elastosis, inflammation, or evidence of vascular injury. The subcutaneous fat and muscle were all normal in appearance.

In summary, the following histological observations were considered significant:

1. The cartilage cells of the epiphyseal plates were profoundly affected by irradiation, and the growth process was interrupted.

2. Following epiphyseal fusion and resorption, no stigma of the previous damage remained.

3. Neither cortical nor cancellous bone nor included marrow showed residual evidence of abnormality.

4. All articular cartilage exposed to irradiation showed, on microscopic examination, evidence of mild degenerative change, save one which showed marked changes, probably due to other causes.

5. There was no evidence of significant abnormality in the synovial membrane, joint capsule, skin, or periarticular soft tissues.

DISCUSSION

Particular attention must be directed toward the possible delayed effects of roentgen treatment, if it is to be applied therapeutically to retard growth of the human limb. In the present study, moderate dosages were utilized, and produced the anticipated inhibiting effect upon the epiphyseal cartilage. The morphological changes in this structure, which appeared soon after treatment, were similar to those previously noted in the rat [1, 3, 4]. Late morphological changes were not comparable with the results in the rat, because the epiphyses of the rat do not fuse with the diaphyses. The present study on the dog showed that fusion and resorption of the epiphyseal plate occurred, and that all evidence of intraosseous damage disappeared. Save for diminished length, the treated bone itself differed only in minor respects from its untreated counterpart. The treated joint was somewhat smaller than the untreated one.

Of utmost importance in this study was the determination of the relative roentgen susceptibility of epiphyseal cartilage as compared with articular cartilage. Articular cartilage in the rat had been found in the authors' studies and in those of others to be comparatively resistant to the roentgen ray [1, 3, 5]. Horwitz and Dillman observed the histological changes in four dogs, given from 3,000 to 8,000 r in fractionated doses over joints when one year of age. These dogs were sacrificed at intervals between twelve and sixteen months after treatment, and no abnormalities were noted in articular cartilages, subchondral bone, synovial tissue, joint capsule, or investing soft tissues. Two other dogs, similarly treated, were followed for longer periods, and showed no roentgenographic evidence of joint disease. These authors state, however: "Despite the experience that much larger doses applied to the more vulnerable joints of our dogs were without immediate and, thus far, remote deleterious effects, it is our experience that very heavy roentgen-ray dosage will affect normal human joints adversely."

Engel found that both fibrocartilage and hyaline cartilage were resistant to large amounts of irradiation.

Contrary to expectations based upon the authors' earlier experiments on the rat, the articular cartilage in dogs showed histological evidence of degenerative change. Since no animal was studied earlier than the fourth month after treatment, it is not possible to state that the damage to the epiphyseal and articular cartilages occurred simultaneously. The damage appeared to increase with time, although in only one of the twenty-four joints could it be classified as severe. This one case of pronounced arthritis was assumed to be due to some unknown cause.

The lesion found in all treated articular cartilages (patella, tibia, femur, radius, ulna, and carpal bones) consisted of disarrangement and diminution of chondrocytes, thinning of the cartilage, and a minor degree of change in the texture of the matrix and scalloping of the cement line. With the one exception noted, there were no striking gross joint changes. The articular surfaces were, for the most part, smooth and perfectly adequate for normal function. It is probable that the durability of these cartilages was less than that in the untreated areas, and that deterioration with continued use would be greater. This was demonstrated by the increased degeneration apparent in those animals sacrificed late in the experiment.

Although one is justified in presuming that these degenerative lesions are the result of the irradiation per se, Horwitz and Dillman found no articular changes in the dogs which they treated at one year of age, after the growth process had ceased spontaneously. In these animals, in which maximum leg length had been attained, no shortening should have resulted; and the trauma caused by limping must have been absent. Furthermore, rats receiving similar amounts of irradiation, but with movement and weight-bearing restricted by confinement in small cages, did not show any such degenerative process. Hence it is possible that the deformity (shortening) produced by irradiation was the basis for the articular lesion, and not the irradiation itself. This problem must remain unsettled,

pending further studies. The bowing of the forelegs which occurred in eight dogs was not sufficiently constant or severe to be considered as a factor in the development of the degenerative joint process.

In the dog, the proportion of growth arising from a given epiphysis was constant. In the tibia, roentgenotherapy of either epiphysis would be expected to produce approximately equal results, as normal growth from the distal and proximal epiphyses is essentially equal. The distal radial epiphysis was found to contribute two-thirds of the longitudinal growth of this bone, and the proximal epiphysis only one-third. Hence artificial inhibition of growth of the proximal epiphysis might be expected to cause only one-half the retardation which would result from arrest of the distal epiphysis.

After irradiation, limited growth continued from the treated epiphysis. In general, it appeared that, with a given dose of irradiation, the degree of retardation was relatively constant. A dosage of 800 r did not produce as much retardation in growth as did dosages of 1,000 r and 1,200 r. Spangler observed that 672 r and 1,992 r, respectively, in divided doses, were not adequate to cause complete arrest of growth in two human cases, and that 2,656 r and 4,300 r, respectively, were sufficient to do so in two other cases. It is believed that complete arrest is not required. Estimation of the amount of shortening desired, knowledge of the proportionate growth index of the various epiphyses, and due regard for the integrity of extra-osseous tissues are factors requiring primary consideration. It is also necessary to take into consideration the data recorded in Table VIII, showing that stimulation of the untreated epiphysis of the irradiated bone usually occurs. Several explanations are possible: The overgrowth might be innately compensatory in character; the minor trauma resulting from limping, due to shortening of the limb, might have acted as a stimulus; or the destructive process in the treated epiphysis might have increased circulation to the bone. This introduces another variable, although possibly predictable, factor to the estimation of anticipated end results.

SUMMARY AND CONCLUSIONS

1. Roentgen dosages of from 800 to 1,200 r were directed over selected joints of six-week-old dogs. The treated area included the joint, epiphysis, and adjacent metaphysis.

2. The epiphyseal cartilage was profoundly affected, and retardation of growth occurred.

3. The articular cartilage of the treated joints showed frank microscopic evidence of degenerative changes, and was not so thick as in the controls. These changes were not sufficient to interfere with joint function during the period of the experiment, and were not apparent on gross examination.

4. There was no evidence of significant abnormality in the adjacent cortical or cancellous bone, synovial membrane, joint capsule, skin, or pariarticular soft tissues.

5. Mild bowing of the treated fore limb occurred in eight of twelve animals. No such deformity occurred in the hind limbs.

6. Although shortening of the treated bone occurred in each instance, there was evidence of stimulation of growth at the untreated epiphysis of the treated long bone. The cause of this stimulating effect is not apparent.

7. The clinical use of roentgen irradiation of growing epiphyses to control longitudinal growth inequalities in children must be considered as experimental, and fraught with some potential dangers. Whether the danger is greater than is incurred in surgical procedures, such as lengthening or shortening of the lower extremity and epiphyseodesis, must await further investigations.

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DISCUSSION

DR. FREDERIC C. BOST, SAN FRANCISCO, CALIFORNIA: The report of roentgen exposure as a means of arresting epiphyseal growth, presented by Dr. Reidy, arouses considerable interest. Thus far, this work is purely experimental, and it should not be applied to the treatment of inequalities of limb length in children. The experiments reported by these authors show definite complications, such as unequal growth of the epiphyses, failure of growth of the epiphyseal body, and some degenerative changes following irradiation. Such complications might lead to serious disturbances in function, which could not be tolerated by the human joint. The fact that the varying doses of roentgen exposure give rise to varying degrees of epiphyseal arrest is of more than passing interest. After further experimental trial, some means might be found to eliminate the complications noted in this study, so that in the future some clinical application might be found for this method of treatment.

DR. J. WARREN WHITE, GREENVILLE, SOUTH CAROLINA: In Dr. Reidy's remarks, there was a question as to why there was some growth at the free end of the bone, even of bone that had received roentgen treatment. I think we can explain that from the fact that roentgen treatment has produced a generalized hyperaemia of the extremity. That is a clue which we can follow in possibly stimulating growth in the short leg.

I was disappointed in the evidence of the arthritis that was found in the dogs' joints. About six or seven years ago, Dr. Warner and I carried on some unpublished experimental work on radiological retardation; and our feeling was, after we had treated five cases in children, that we were unjustified in continuing, in view of the fact that we were getting skin damage with our animals which were being treated intensively. It is apparent that, until we get a more encouraging report from these investigators, further retardation by roentgen rays should be postponed.

DR. D. B. PHEMISTER, CHICAGO, ILLINOIS: The interesting investigative work presented has emphasized the fact that much remains to be accomplished before growth-arrest procedures for equalization of length in the extremities reach their final stage of perfection. If retardation of bone growth by roentgen rays is to be utilized clinically, it will be for equalization of length of the lower limbs. In the upper extremity, the indication is for equalization of the length of the radius and ulna in cases in which either bone is short as a result of growth arrest at the lower end. This calls for complete arrest of growth at the lower end of the other bone, combined in some cases with resection of a segment of the metaphysis, which can only be accomplished by operation.

FUSION OF THE HIP IN CHILDREN

THE CHANDLER METHOD*

BY CHARLES N. PEASE, M.D., CHICAGO, ILLINOIS

From the Children's Memorial Hospital, Chicago

The approach to the problem of tuberculosis of the hip joint should be directed to the one purpose of eradicating the disease as rapidly as possible with a minimum of risk to the patient. This purpose may be accomplished by the use of the combined intra-articular and extra-articular fusion of the hip joint described by Chandler.

Operations designed to transfer femoral weight-bearing from the hip joint to other regions of the pelvis or to immobilize the hip joint by extra-articular means are not entirely desirable. These methods circumvent the pathological process, which becomes a potential source for metastatic spread. Eikenbary and Lecocq demonstrated an active tuberculous process in the hip joint, despite an excellent extra-articular fusion. The area lying between the superior portion of the femoral neck and the graft, which extended from the trochanter to the ilium, contained tuberculous granulation tissue. A similar observation was made while the author was reviewing one of the cases presented.

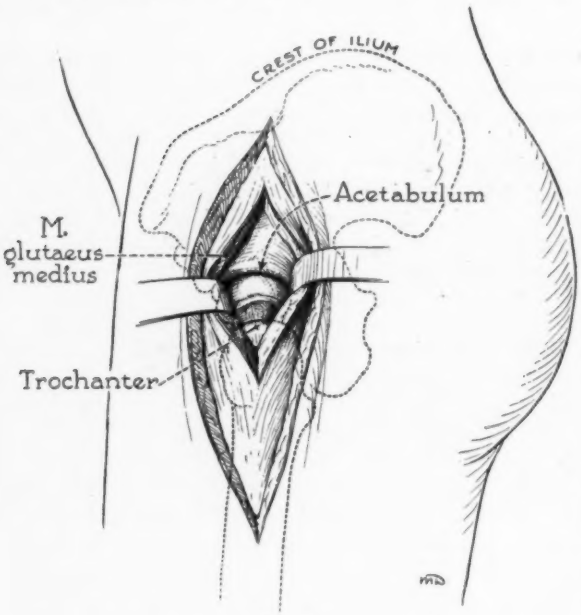

FIG. 1

Lateral incision extending from crest of ilium to five inches below the greater trochanter.

What the Chandler fusion strives to accomplish is not only elimination of motion at the hip joint, but also obliteration, as much as possible, of the areas of bone destruction with the associated soft-tissue involvement. It is a simple procedure; it is one that can be done rapidly; and it is not attended by great danger.

By this operation, an attempt is made to replace the local area of disease by a coalescence of transplanted bone which, in the healing process and together with the surrounding fibrous-tissue formation, obliterates the pathological process. The removal of as much of the necrotic and tuberculous granulation tissue as possible and the substitution of healthy bone produce a favorable site for new-bone formation and connective-tissue growth. The use of the trochanter and a portion of the shaft of the femur, together with bone chips, to produce fusion will be described in detail later. These materials form the foundation from which young connective-tissue cells infiltrate and spread, laying the network for new-bone formation which will cement the affected area. Surrounding the new bone, the fibrous-tissue formation, stimulated by the surgery, will simultaneously invade what remains of the tuberculous granulations and will ultimately replace the latter, thus reversing the process of the disease.

* Read at the Annual Meeting of The American Academy of Orthopaedic Surgeons, Chicago, Illinois, January 30, 1947.

FIG. 2

FIG. 3

FIG. 4

Fig. 2: Osteoperiosteal flaps are elevated, after which trochanteric graft is removed. Recess in ilium is made at margin of acetabulum.
Fig. 3: Articular cartilage has been removed from head of femur and acetabulum. Joint space has been packed with bone chips taken from femoral shaft or ilium.
Fig. 4: Trochanteric graft has been turned end for end, and has been driven into recess in ilium. Osteoperiosteal flaps are sutured over graft.

FIG. 5-A
A. S., male, aged nine. Tuberculosis of right hip.

FIG. 5-B
After fusion of right hip.

FIG. 5-C
Two months after operation.

FIG. 5-D
Six years after operation.

FIG. 5-B
After fusion of right hip.

FIG. 5-D
Six years after operation.

FIG. 6-A

D. L., male, aged seven. Tuberculosis of left hip. Boy failed to return to Clinic.

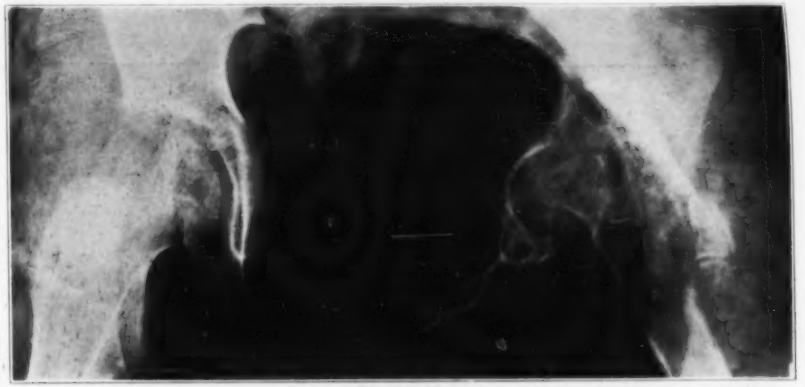

FIG. 6-C
One week later hip fusion was done.

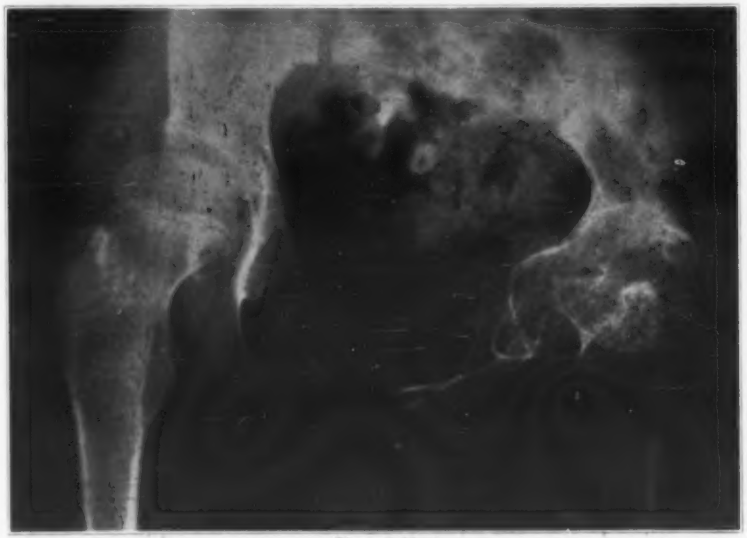

FIG. 6-B
Condition of hip upon return to Clinic after five years.

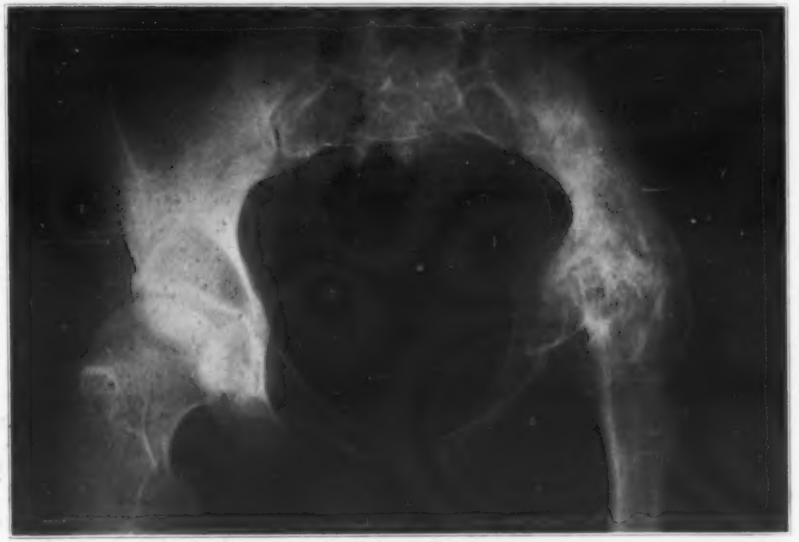

FIG. 6-D
Eleven years after operation.

FIG. 7-A

E. R., female, aged eleven. Tuberculosis of left hip.

FIG. 7-B

After fusion of left hip.

FIG. 7-C

Two years after operation.

This study consisted of a five-year follow-up of twenty-eight children upon whom the Chandler operation had been performed. Twenty-three fusions were done for tuberculosis of the hip, four for quiescent pyogenic infection, and one for congenital dislocation of the hip which had been operated upon with a poor result. Ages varied from fourteen months

FIG. 8-A

A. R., male, aged six. Tuberculosis of right hip.

FIG. 8-B

Appearance of hip after two years. Patient had had cast treatment elsewhere.

FIG. 8-C

Eleven years after operation.

to twelve years, the average age being seven and seven-tenths years. Patients were not selected on the basis of risk, as demonstrated by the fact that three children also had tuberculosis of the spine, three had tuberculosis of the kidney requiring nephrectomy, two had tuberculosis of the elbow joint, one had tuberculosis of the sacro-iliac joint, and one had tuberculosis of the knee joint.

FIG. 9-A

H. N., male, aged ten. Tuberculosis of left hip.

Pseudarthrosis occurred in three cases. One child was operated upon three times before a satisfactory result was obtained, while three children were operated upon twice.

There were no deaths immediately following surgery, but one child, who also had a tuberculous knee joint and a tuberculous kidney, died from tuberculous meningitis one year following the hip fusion. Two children in whom tuberculosis of the cervicothoracic and cervical spine had developed, one and one-half and two years, respectively, following hip fusion, also died from tuberculous meningitis.

FIG. 9-B

Two years after operation. Hip sinus was draining. Tuberculous kidney had been removed.

FIG. 9-C

Thirteen years after operation.

TECHNIQUE

Hibbs first used the trochanter in extra-articular fusion of the hip, but Chandler employs it in the combined operation. Although the technique of this operation has been reported previously, a brief description of the method may be repeated at this time. The patient is placed on his side, and the hip to be operated upon is elevated at an angle of 45 degrees. A lateral incision is made, extending from just below the crest of the ilium to the junction of the upper and middle thirds of the thigh. There is no extensive separation of fascial or muscle layers; only enough dissection is done to facilitate suture. The incision is deepened by splitting the fibers of the tensor fasciae latae, and is then carried through the vastus lateralis and the periosteum, and upwards through the glutaeus medius parallel to the muscle fibers, exposing the superior portion of the femoral neck and crossing the hip joint at right angles to the upper acetabular margin (Fig. 1). With a wide osteotome, bone flaps are elevated medially and laterally from the base of the femoral neck downward for three to five inches (Fig. 2), depending upon the age of the patient. The acetabulum and adjacent ilium are exposed by reflecting the joint capsule.

With an osteotome, a graft, consisting of a generous portion of the trochanter and including three to five inches of the shaft of the femur, is made, by means of parallel incisions into the bone, which converge distally. The graft is removed gently and placed in a gauze dressing saturated with Ringer's solution. The femoral neck and head come plainly into view. The articular surfaces of the head of the femur and the acetabulum are removed with a curette or chisel. On some occasions, the hip has been dislocated by slight adduction and external rotation of the shaft of the femur; this facilitates removal of the articular cartilage.

A hinged flap is elevated from the ilium at or slightly above the acetabular margin by inserting an osteotome at the selected site. A recess is made beneath this flap to receive the graft.

Bone chips are taken from the margins of the shaft of the femur where the graft was removed or from the exposed ilium, and are firmly packed into the superior portion of the hip joint (Fig. 3). The trochanteric graft is then turned end for end and driven into the recess in the ilium (Fig. 4). The thigh may be adducted to facilitate the driving of the graft into the ilium. Upon abduction of the femur, the graft is locked into position. The osteoperiosteal flaps, made prior to the removal of the graft, make a closure favorable to osteogenesis.

After closure of the wound, a double spica cast is applied, extending to the toes on the side operated upon and to the knee on the opposite side. After a period of from six weeks to ten weeks, this cast is replaced by a single spica cast, which extends to just above the malleoli.

The limb in plaster should be in complete extension and in sufficient abduction to maintain the locked position of the graft, even if it has to be extreme abduction. This latter position is not considered optimum, but eradication of the disease is the most important requisite and any resulting deformity can be corrected later.

Despite the wide abduction and extension positions of the hip, it has never been necessary to perform an osteotomy to correct these positions. In all instances, however, a decrease in the degree of abduction has occurred during growth, by virtue of the powerful action of the adductor muscles (Figs. 5-B, 5-C, 5-D, 6-C, 6-D, 7-B, and 7-C).

AFTER-CARE

The postoperative care of these children may differ from the conventional type which is being used today. If the child's general condition is satisfactory, no restraint is used to limit activity; instead, it is encouraged. If a child shows a desire to stand or walk while he is in plaster, he is permitted to do so. This is an attempt to return the patient to a more

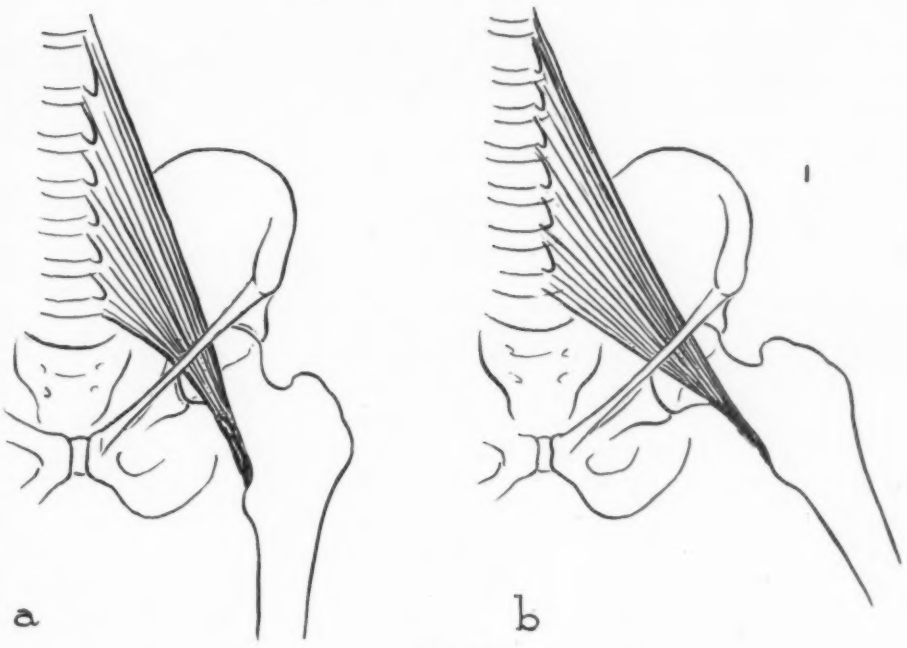

FIG. 10

a: Schematic drawing of iliopsoas muscle in position for its most efficient pull.
b: With limb abducted, iliopsoas does not exert its greatest power. With the elimination of adductor force by obturator-nerve section, there should be less likelihood of flexion as well as of adduction deformity.

normal physical status. With the approach to normal physical activity, conditions are favorable for improvement of all bodily functions, thereby stimulating physical and chemical processes conducive to tissue repair.

The minimum time in plaster was four months; the maximum, twenty-six; the average, eleven months.

Transfusions with whole blood or packed cells are given if the erythrocyte count is below normal. A high-caloric diet and one rich in protein and minerals is desirable. Cod-liver oil is given daily.

When the chart indicates that no gain in weight has been made, complete rest is ordered. Roentgenograms of the hip are examined for possible active disease, and evidence of metastasis is looked for in other parts of the body.

Routine guinea-pig inoculation with urine from all patients under active treatment should be done every six months, since two of the three patients who had concomitant tuberculous kidneys exhibited no urinary symptoms. It was only after positive guinea-pig findings that pyelograms were made which demonstrated destructive processes on one kidney of each child.

Draining sinuses occurred in four patients postoperatively. Discharge persisted for two, ten, twenty-four, and thirty-two months, respectively. All hips fused solidly in spite of the discharging sinuses.

Adduction and flexion deformity occurred in three cases, which required correction by osteotomy. There are two other patients who are in need of osteotomies, because of adduction and flexion deformity.

OBTURATOR-NERVE SECTION

The power of the adductor muscle was not only a factor in producing postoperative deformity, but was also considered a possible cause for failure of fusion. Elimination of this force should favor a more satisfactory end result in hip fusion.

FIG. 11-A
L. U., female, aged six. Tuberculosis of right hip.

FIG. 11-B
Six years after operation.

FIG. 12-A
A. H., male, aged six. Tuberculosis of left hip.

FIG. 12-B
Five years after operation.

FIG. 13-A
V. M., female, aged ten. Tuberculosis of right hip.

FIG. 13-B
Two years after operation.

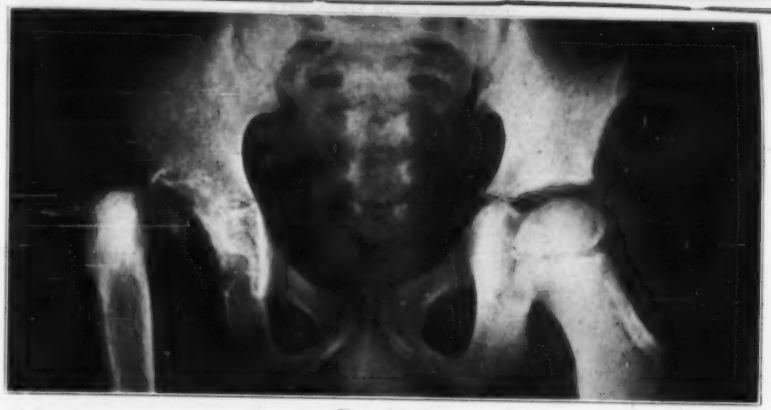

FIG. 14-A
W. H., male, aged seven. *Bacteroides funduliformis* infection of right hip.

FIG. 14-B
Three years after operation.

FIG. 15-A

FIG. 15-B

Fig. 15-A: D. O'D., female, aged four. Tuberculosis of left hip and sacro-iliac joint.
Fig. 15-B: Six years after fusion of right sacro-iliac and left hip joints. Note calcified abscess in right pelvis. This child also had had a tuberculous kidney removed.

FIG. 16-A
R. L., male, aged six. Tuberculosis of neck of femur.

FIG. 16-B
Three years after removal of sequestrum. Note involvement of acetabulum and capital epiphysis.

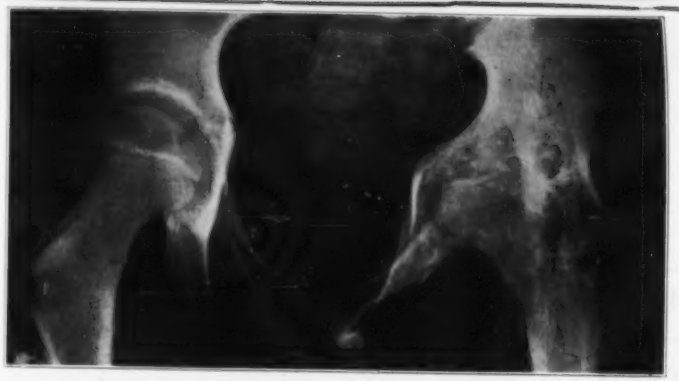

FIG. 15-C
Five years after operation.

FIG. 16-D
Showing tuberculosis of lower portion of fifth lumbar vertebra. Spine fusion had been performed two years before hip fusion. This case demonstrated another good reason for use of a short graft for spine fusion in tuberculosis.

FIG. 16-D

Chandler has been doing a preliminary intrapelvic, extraperitoneal section of the obturator nerve on patients requiring hip arthroplasty, in order to overcome postoperative adductor spasm. Such section of the obturator nerve has been performed recently in conjunction with hip fusion in six children. It is hoped that this will eliminate pseudarthrosis and adduction deformity. In addition, this procedure is expected to prevent the flexion deformity of the hip, which occurs simultaneously with adduction. Theoretically, this nerve section should result in adduction, because the iliopsoas does not exert its fullest power with the leg in abduction (Fig. 10). Whether or not obturator-nerve section will result in a more favorable condition for fusion in the six cases in which it has already been performed cannot be stated yet, since sufficient time has not elapsed to observe the final results.

COMMENT

The method described has simplified hip fusion and by its use excellent end results have been obtained. Some surgeons have objected to operating through an area with an active tuberculous process. However, the same objections are not usually raised in the case of active tuberculosis of the knee joint. The study of the cases herein reported does not indicate that there have been any harmful effects; but, on the other hand, it has shown that definite benefit is derived from direct early elimination of an active tuberculous process.

The combined intra-articular and extra-articular fusion stimulates not only new-bone formation for the production of fusion, but also considerable fibrous-tissue formation, which replaces tuberculous granulation tissue and obliterates the infected areas in the same manner as thoracoplasty.

Obturator-nerve section, combined with hip fusion, appears to hold promise of a decrease in the incidence of pseudarthrosis and deformity.

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TUBERCULOSIS OF THE HIP IN CHILDREN

Certain Roentgenographic Manifestations, Secondary Changes in the Extremity, and Some Suggestions for a Program of Therapy*

BY H. R. MCCARROLL, M.D., AND R. D. HEATH, M.D., ST. LOUIS, MISSOURI

From the Shriners' Hospital for Crippled Children and the Department of Surgery, Washington University School of Medicine, St. Louis

Tuberculosis of the hip in children, despite years of study and varied types of management by innumerable investigators, still stands today as one of the most difficult problems encountered in working with crippled children. In these cases, the ultimate aim for the optimum end result can be simply stated as arthrodesis of the hip; but this is where the trouble begins. To accomplish arthrodesis in a young child early enough to prevent massive destruction of all bone structures in the region of the hip, and to prevent the extreme secondary changes in the extremity which result from prolonged fixation, is no simple task. It is with this aim in mind, and with the desire to stress the extreme secondary manifestations frequently encountered in these extremities, that this presentation has been undertaken. It is based on a study of eighty-six cases at the St. Louis Unit of the Shriners' Hospitals for Crippled Children.

The various clinical manifestations of tuberculosis of the hip are well recognized. We do wish, however, to show two types of early involvement which may be encountered. Phemister and Hatcher, in 1933, in their classical presentation of the pathological changes in tuberculous arthritis, stated that, in the majority of cases, the initial osseous invasion of the hip occurred in the juxta-epiphyseal region of the neck of the femur. In those of our cases in which the early osseous lesion could be determined, the cancellous bone on the acetabular side of the joint was more frequently involved than the metaphyseal region of the femoral neck. A typical case with primary involvement of the acetabulum is shown in Figures 1-A to 1-F. We have, however, seen an occasional case in which the initial lesion occurred in the metaphyseal region of the femoral neck (Fig. 2-A). Such lesions, although they may be slower in progression, usually result in the same massive destruction of the hip joint as shown in this case, and present an equally difficult problem. In most of the cases seen in this Clinic, the disease had advanced to such a degree that it was impossible to state whether the initial invasion was synovial or osseous in nature, or on which side of the joint space the initial osseous invasion had occurred. From a purely practical standpoint, this is of little importance, since total destruction of the joint almost invariably follows either type.

The onset of the disease in very young children, two to five years of age, is not uncommon. There is usually little resistance on the part of these individuals to the infection, and massive destruction in the joint follows very rapidly. Also, in these children, bone development is still in its infancy, and we have very poor structures with which to undertake surgical fixation of the joint. Because of this fact, it was our policy, prior to 1940, to maintain continuous and complete immobilization in plaster-of-Paris spicas until the age of eight or nine years. This age was chosen arbitrarily as the age when bone development was sufficiently advanced so that arthrodesis of the hip could be reasonably expected after insertion of a bone graft by one means or another. Our other theory, in following this plan of treatment, was that surgery should be postponed until the destruction had reached its maximum point, and the development of an area of increased bone density about the defect had shown some attempt to limit the process (Figs. 1-B and 2-C). This line of

* Presented at the Annual Meeting of The American Academy of Orthopaedic Surgeons, Chicago, Illinois, January 30, 1947.

FIG. 1-A

FIG. 1-B

FIG. 1-C

Fig. 1-A: Case D. K., at three years of age. Roentgenogram shows early tuberculosis of the left hip with a primary osseous lesion on the acetabular side of the joint. Symptoms at this time had been present for only a few months.

Fig. 1-B: Three years later. Roentgenogram shows massive destruction of the entire acetabular aspect of the joint with secondary destructive changes in the femoral head and neck. Beginning sclerosis of the bone margin about the superior edge of the destructive lesion is also evident.

Fig. 1-C: Six years later. Appearance of hip, six months after extra-articular arthrodesis with iliac-bone graft.

Symptoms at this time had been present for only a few months.

Fig. 1-B: Three years later. Roentgenogram shows massive destruction of the entire acetabular aspect of the joint with secondary destructive changes in the femoral head and neck. Beginning sclerosis of the bone margin about the superior edge of the destructive lesion is also evident.

Fig. 1-C: Six years later. Appearance of hip, six months after extra-articular arthrodesis with iliac-bone graft.

FIG. 1-D

FIG. 1-E

FIG. 1-F

Fig. 1-D: Showing excellent arthrodesis, fifteen years after onset and nine years after operation.

Fig. 1-E: After six years of plaster fixation, shortening of five and one-half inches was obvious. Excellent arthrodesis had occurred. Patient had moderate relaxation of the knee joint and medial bowing of the tibia.

Fig. 1-F: Roentgenographic appearance of knee joint after six years of plaster fixation, showing the complete destruction of the epiphyseal lines and marked changes in these regions.

reasoning is justified from the results, since arthrodesis is more easily obtained in a hip of this type than in that of a younger child or in the presence of a lesion which is still progressing rapidly. Of forty-three hips immobilized for from two to eight years in preparation

FIG. 2-A

FIG. 2-B

Fig. 2-A: Case D. R., aged six years. Roentgenogram shows early tuberculosis of the left hip, with primary osseous lesion in the metaphyseal region of the neck, and partial dislocation of the hip from muscle spasm. The hip joint itself was still uninvolved.

Fig. 2-B: Five years later. Early reduction had been brought about by skin traction, and position was maintained with plaster fixation. Destructive lesion was still localized to the femoral neck and contained a definite sequestrum. Destruction of the hip joint had not occurred.

FIG. 2-C

FIG. 2-D

Fig. 2-C: Seven years later. Massive extension of the destructive process had occurred, with complete disintegration of the hip joint. Limiting wall of increased bone density is seen about the periphery of the defect.

Fig. 2-D: Six months after an intra-articular arthrodesis with a massive tibial-bone graft, extending from the ilium into the trochanter. Absorption of the graft at its mid-point, by invasion of the tuberculous tissue, had begun.

FIG. 2-E

FIG. 2-F

Fig. 2-E: Ten years after onset and three years after arthrodesis, the bone graft had disappeared and there was no evidence of bony union. The defect in the acetabulum and in the femoral neck, however, had filled in considerably.

Fig. 2-F: Twelve years after onset and five years after arthrodesis, complete healing had taken place. The joint space was obliterated and the entire cavity was filled with new bone.

Fig. 2-G: Photograph of D. R. at age of fourteen, after five years of plaster immobilization. Shortening of four inches was still present three years after epiphyseal arrest in the normal extremity.

FIG. 2-G

for arthrodesis, satisfactory results were obtained in thirty-one instances. Of the thirty-one satisfactory fusions, twenty-five occurred following the first attempt, while six hips required a second operation. There were nine failures in this group; the results were unknown in three.

In the entire series, arthrodesis has been attempted in seventy-two cases in which adequate follow-up studies have been possible and in which arthrodesis has been delayed for varying periods, according to the age of the patient. These follow-up studies have extended over periods which have varied from three years to twelve years. The results in this entire series are shown in Table I; the percentage of satisfactory fusions is almost identical in the two groups. Tables II and III show results according to the type of arthrodesis and the type of graft used. Satisfactory results in 75 per cent. of the cases is a higher average than in most reports in the literature. There may be two explanations for this higher percentage. First, no adults are included in this series, and it is possible that complete obliteration of the joint space may be more difficult to obtain in adults. The second factor may be the length of follow-up studies in these patients. Many patients, classified as "failures" four to five years after operation, showed excellent results and solid arthrodesis eight to ten years afterwards (Figs. 3-C and 3-D). The length of follow-up is, therefore, definitely important in determining the percentage of solid fusions. In the interval, many of these

TABLE I

RESULTS OF ATTEMPTED ARTHRODESIS OF THE HIP

	Number of Hips	Fusion		Failures	Percentage of Fusion	End Result Unknown
		After First Operation	After Second Operation			
Entire series	72	41	11	17	75	3
Hips immobilized 2 to 8 years before fusion	43	25	6	9	72	3

TABLE II

RESULTS AS TO TYPE OF ARTHRODESIS

	Solid Fusion	Failure	Unknown
Intra-articular	29	10	2
Extra-articular	23	7	1
Total	52	17	3

same patients had had subtrochanteric osteotomies for correction of a deformity, and it is possible that this may have contributed to their eventual solid arthrodesis.

As regards the local lesion, these results are not unsatisfactory; yet, when we consider the individual as a whole, this form of treatment must be classified as poor, because of the extreme secondary changes which occur in these extremities, subjected to years of immobilization and inactivity. As a rule, the end-result studies showed these patients to have extremities which were several inches shorter, atrophied, and with knees so relaxed that lateral motion often equaled the degree of flexion and extension (Figs. 1-E, 2-G, and 4-A). The long bones were often so fragile that spontaneous fractures were not infrequent. Occasionally, genu valgum and medial or anterior bowing of the tibia were also seen. In short, these individuals were as disabled from these secondary complicating factors as

TABLE III

RESULTS AS TO TYPE OF GRAFT USED

	Solid Fusion	Failure	Unknown
Tibial graft	17	6	
Iliac graft	20	7	
No graft	1	1	
Trochanteric	2		
Iliac with calcium insufflation	2		
Osteoperiosteal	2		
Subtrochanteric osteotomy only	1		
Combination of procedures	7	3	
Total	52	17	3

FIG. 3-A

FIG. 3-B

Fig. 3-A: Case A. D., aged three years. Roentgenogram shows massive destruction of the right hip from tuberculosis. Obviously the primary osseous lesion in a case of this type cannot be stated.

Fig. 3-B: Four months later, immediately after an intra-articular type of fusion with the insertion of a massive tibial-bone graft.

FIG. 3-C

FIG. 3-D

Fig. 3-C: Three years later, roentgenogram shows some filling in of the destructive lesion, but complete failure as far as the arthrodesis itself is concerned.

Fig. 3-D: Twelve years after arthrodesis, showing complete obliteration of the destructive lesion and bony trabeculae traversing the entire joint space. Subtrochanteric osteotomy had been performed in the interval.

TABLE IV

SHORTENING RESULTING FROM PROLONGED IMMOBILIZATION

Period of Immobilization	Number of Hips Involved	Maximum Shortening (*Inches*)	Average Shortening (*Inches*)
2 to 8 years (Average, 4 years)	43	7	2.7
3 years or more	24	7	3.3

they originally had been from the hip-joint tuberculosis itself. Of forty-three hips which were completely immobilized for from two to eight years, twenty-eight showed shortening of from two to seven inches. There was an average fixation time of four years in the forty-three patients, with an average shortening of 2.7 inches (Table IV). In twenty-four patients immobilized three years or longer, an average shortening of 3.3 inches was found. The degree of shortening, in some instances at least, seemed in direct proportion to the period of complete immobilization. Eleven patients showed shortening of four inches or over, which is certainly enough to be classified as a major deformity and handicap. One patient, immobilized for eight years, showed shortening of seven inches (Fig. 4-A). Other

FIG. 4-A

FIG. 4-B

Fig. 4-A: Case S. D., aged twelve years. Photograph of patient, showing seven inches of shortening following eight years of plaster immobilization. Excellent arthrodesis of the hip had been obtained.

Fig. 4-B: Anteroposterior view of the corresponding knee joint, showing complete destruction of the lower femoral epiphyseal line and only a small marginal remnant of the upper tibial epiphyseal line. The upper fibular epiphyseal line remains open.

FIG. 4-C

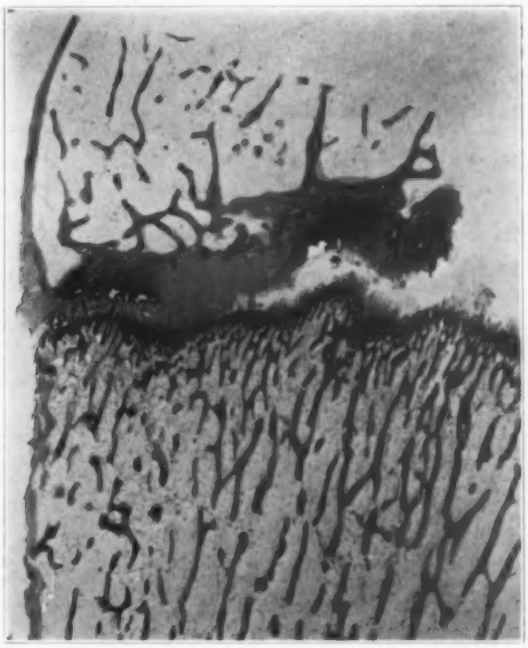

FIG. 4-D

Fig. 4-C: Low-power magnification of lower femoral epiphyseal line of the involved extremity, after eight years of plaster fixation. Only a remnant of the epiphyseal cartilage remains, and this lies parallel to the long axis of the bone and disappears entirely a short distance below the surface.

Fig. 4-D: Low-power magnification of normal lower femoral epiphyseal line in the uninvolved extremity.

major operations were often necessary in an attempt to compensate for this shortening, but their consideration is not within the scope of this discussion.

We were at a loss to account for the extreme degree of shortening which occurred in these patients. The upward displacement of the extremity as a result of the destruction at the hip joint, and the complete loss of the upper femoral epiphysis, which accounts for only 12 per cent. of the growth of the lower extremity, could not possibly explain the extreme shortening which followed. It finally occurred to us to take roentgenograms of the other epiphyses of the extremity, and these revealed changes which could easily explain the discrepancy. Premature closure of the epiphyses, with deformity of the epiphyseal plates and metaphyseal areas, was revealed (Figs. 1-F and 4-B). These changes were described by Gill in 1944. Sections for biopsy were obtained from the lower femoral epiphyseal lines in the involved extremity and in the normal extremity of the patient with seven inches of shortening. These revealed only a remnant of the epiphyseal line in the involved extremity (Fig. 4-C), as compared with a perfectly normal epiphyseal structure on the other side (Fig. 4-D).

As stated previously, of forty-three hips treated by prolonged preliminary plaster fixation and rest, solid fusion occurred in thirty-one instances after surgical arthrodesis by means of bone grafts. However, the secondary changes resulting in the extremities were so serious that it seemed unwise to continue this plan of therapy. We decided, therefore, to attempt earlier operative fixation in every instance where the general condition of the patient would permit. Plaster fixation of the hips was used for approximately six months after the diagnosis had been established, in order to permit the early acute symptoms to subside and also to improve the general condition of the patient as much as possible. This was then followed by attempted arthrodesis of the hip. While it was clearly understood that early intra-articular arthrodesis was inadvisable and unsuccessful in the majority of instances, we still attempted four such operations. Draining sinuses followed in three of the

FIG. 5-A

FIG. 5-B

FIG. 5-C

Fig. 5-A: Case S. L., aged five years. Very early tuberculosis of the left hip. Intra-articular arthrodesis was performed six months later with a heavy tibial graft.
Fig. 5-B: Six months after the arthrodesis, showing complete absorption of the graft opposite the joint space and extension of the destructive process.
Fig. 5-C: Four and one-half years after operation. There had been some filling in of the process, but arthrodesis had not yet occurred. Motion was still demonstrable at this time and two draining sinuses persisted. With the degree of healing shown, it is possible that arthrodesis may ultimately occur; but, if it does, the intra-articular arthrodesis cannot be given credit for the fusion.

arthrodesis cannot be given credit for the fusion.

FIG. 6-A

FIG. 6-B

FIG. 6-C

Fig. 6-A: Case V. F., aged six years. Tuberculosis of the right hip, three years after onset of symptoms.

Fig. 6-B: Roentgenogram, showing hip after extra-articular arthrodesis by means of massive tibial graft; this was anchored to shaft below by means of threaded wires which were later removed.

Fig. 6-C: Roentgenogram of hip, four years after arthrodesis. Ultimate solid fusion appeared certain, but pseudarthrosis of the graft was still present. The graft, therefore, had failed to afford fixation.

FIG. 7

FIG. 8-A

FIG. 8-B

Fig. 7: Case P. K., aged thirteen years. One year after Brittain type of arthrodesis for early tuberculosis of left hip. There was complete absorption of the mid-portion of the tibial graft, which was probably due to invasion of the graft by tuberculous granulations. At the time of operation, no abscess was encountered, and it was thought that the graft had not entered tuberculous tissue.

Fig. 8-A: Case D. S., aged eleven years. Roentgenogram of hip one year after Brittain arthrodesis. At the time this graft was inserted, a large tuberculous abscess was encountered, and the graft unquestionably entered the joint space. There has now been complete absorption of the medial portion of the graft, due to invasion by the tuberculous process. In spite of this lack of fixation, the joint is symptom-free, and weight-bearing with the aid of crutches is permitted.

Fig. 8-B: Even though solid arthrodesis of the hip has not occurred, the length and contour of the extremity have been maintained, and the patient is active with the aid of crutches.

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FIG. 9

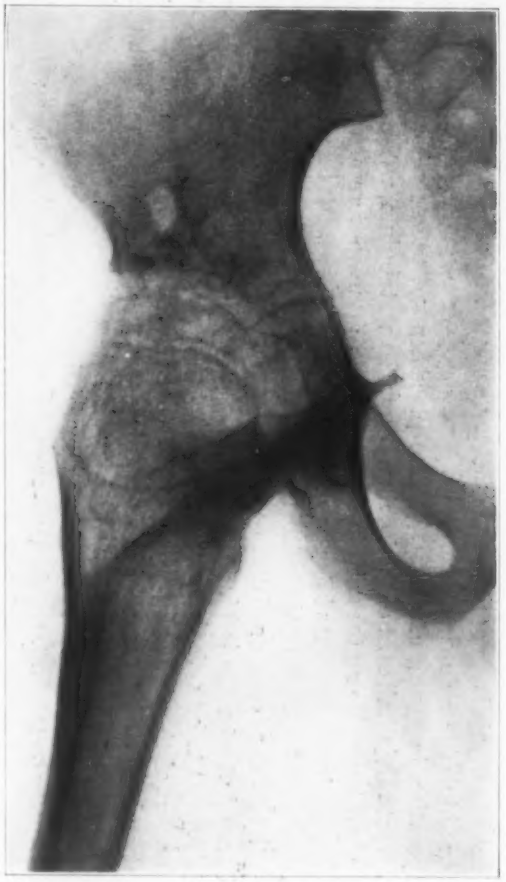

FIG. 10-A

FIG. 10-B

Fig. 9: Case P. D., aged seven years. Appearance of hip one year after Brittain arthrodesis. The graft seems to be anchored at each end and adequate to afford support.

Fig. 10-A: Case J. B., aged seven years. Roentgenogram of right hip one year after Brittain arthrodesis; the graft appears to be firmly anchored at each end.

Fig. 10-B: The length and contour of the extremity have been preserved. Some abduction is present.

cases, and dissolution of the graft promptly occurred in all four cases (Figs. 5-A to 5-C). In only one of the four cases has solid fusion resulted, while in another, some indication of possible ultimate arthrodesis is evident after four and one-half years. Difficulties encountered in these four cases were such that we did not consider the continuation of such a policy justified.

Our next move was the use of a massive extra-articular tibial graft, bridging the joint space from the wing of the ilium to the greater trochanter. A hole was cut in the denuded ilium well above the hip joint, into which the proximal end of the graft was wedged. The distal end of the graft was placed in a groove, cut between the greater trochanter and the base of the femoral neck. In some instances, the entire greater trochanter was removed, the graft was interposed, and both were anchored to the shaft again by means of threaded wires. Bone chips from the tibia and from the ilium were scattered about the tibial graft to fill the defect between the graft and the ilium above the joint level. Here again, however, the results were not encouraging, and the graft often failed to serve as a permanent support (Figs. 6-B and 6-C).

At this time the Brittain arthrodesis was reported in the American literature [4] as being quite satisfactory, and we turned to it in the hope that this might serve as a solution to the problem. Six such operations have been done in patients with early lesions, and we are still not convinced that this is an entirely satisfactory answer for the management of the early tuberculous hip. The following technical difficulties have been encountered in performing the operation in young children: (1) The placement of the osteotome and the large tibial graft into the small area of the ischium below the acetabulum, without entering the hip joint and without placing the graft in the area of the obturator foramen, is difficult. With the former, the fusion becomes intra-articular in type; and with the latter, a smaller bed of bone is available for fixation of the tibial graft. (2) The distal fragment of the femur should be completely displaced medially, so that this fragment completely bridges the span of tibial graft between the ischium and the trochanteric area of the proximal fragment. This has proved to be a difficult accomplishment in young children, even when the entire circumference of the limiting periosteum has been cut. Such displacement of the distal fragment and the maintenance of this position are more difficult in young children than in adults, even when the extremity is widely abducted. A review of the cases reported in the literature shows that other authors have apparently had similar difficulties.

Follow-up studies on this series of six cases are not available at this time. The youngest patient in this group is four years of age and the oldest is thirteen years. Four of them have been followed for over one year. In two of these cases (Figs. 7 and 8-A), absorption of a portion of the graft had occurred by the end of the first year. This was undoubtedly due to invasion by tuberculous granulation tissue. In two other cases (Figs. 9 and 10-A), the graft seems to be united at each end, and the patients are walking with the aid of crutches. Yet, the degree of fixation is not very great, and there has been little, if any, change in the appearance of the hip joints. Over a period of years, however, complete obliteration of the joint space may occur. In this series of seventy-two hips upon which arthrodesis has been attempted, many hips, as stated previously, could be classed as solidly fused, after follow-up studies of eight to ten years, in which the results would have been classed as failures after four to five years.

An important point in the selection of cases suitable for the Brittain arthrodesis is to make sure that the portion of the ischium to be used has not been invaded by the tuberculosis. Unless normal bone is present at this point for the insertion of the bone graft, an extra-articular type of arthrodesis is impossible, and the primary purpose of the operation has been lost. Brittain states that tuberculous disease more frequently extends upward into the ilium than downward into the ischium; in fact, he states that the latter is extremely rare. Other authors [2,4] have verified this statement. This may be true in the very early phases of the disease; but, if the process has been present for a moderate length of

time, destruction of the ischium is very common. Of eighty-three patients in this series with adequate roentgenographic studies, extension into the ischium for a significant distance below the acetabulum was present in sixty-three instances (76 per cent.). This obviously rendered these patients totally unsuitable for surgery of this type. As a matter of trial, this operation was performed upon one patient with obvious involvement of the ischium. Follow-up studies on this patient are not yet available.

In spite of these difficulties and considerations, however, the Brittain arthrodesis seems to offer as good a possibility for an early, successful arthrodesis as is available at present. It should be remembered that to attain good arthrodesis of a tuberculous hip in a young child, when the disease is still in the active phase, is a very difficult task, and there is no entirely satisfactory procedure available. When we consider the crippling effect of secondary changes in extremities that have been immobilized for many years prior to arthrodesis, however, we must admit that some form of early operative fixation is justified and should be attempted. It is with this in mind and in an attempt to activate the diseased extremities as soon as possible, that the Brittain arthrodesis will be given further trial. Certainly a procedure of this type offers some hope of our being able to preserve the length and contour of the extremity (Figs. 8-B and 10-B). Since these patients now have active use of their extremities, it seems reasonable to assume that severe secondary changes in the extremities can be prevented. (Compare with Figures 1-E, 2-G, and 4-A.)

An attempt has been made to rationalize early treatment of tuberculosis of the hip from the knowledge derived in this study, which has extended over a period of several years. The young child with a tuberculous hip is immobilized in a plaster spica for a period of six months, during which time an attempt is made to improve his condition as much as possible by adequate diet, rich in milk and vitamins, and by general supportive care. If the general condition is suitable at the end of six months, a Brittain type of arthrodesis is attempted or, if this is not applicable, some other extra-articular type of fixation is done. The patient is again immobilized in a plaster spica for from six to twelve months, depending upon the degree of union of the graft, during which time adequate general care is maintained. Immobilization is then discontinued, and the patient is allowed to become ambulatory with the aid of crutches, and is permitted to use the hip and extremity increasingly. Even if the arthrodesis fails, active use of the extremity is allowed at this time, in order to ensure against damage to epiphyseal structures by prolonged fixation. A second attempt at arthrodesis is postponed until a later date, and use of the extremity is permitted and encouraged during the interval.

In those instances where the patient's condition is not considered suitable for surgery, plaster fixation is maintained for six months in order to allow the acute phase of the process to subside, after which active use of the extremity is permitted and weight-bearing is instituted, if possible. In some instances, deformities at the hip will follow, but these can be corrected more easily than the deformities occurring in the extremity as a whole, as the result of prolonged fixation and inactivity.

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DISCUSSION

DR. ROBERT PERLMAN, CINCINNATI, OHIO: I am in hearty accord with Dr. McCarroll in his idea of attempting to forestall the secondary changes in the extremity, which result from chronic, destructive tuberculosis of the hip and its treatment. Will this problem be solved before a more direct method of approach is made on the tuberculous process itself, comparable to the use of penicillin in osteomyelitis? Can we avoid long periods of immobilization? May we permit early activity and early partial, protected weight-bearing of the involved extremity? Dr. McCarroll may have the answer in his suggestions of early operation and early activity.

That arthrodesis of the joint is a most suitable form of aid in the arrest of the tuberculous process, is widely accepted. The controversy arises as to which method of arthrodesis best meets the need in any particular case. Dr. McCarroll obtained fusions in 75 per cent. of his cases. About 18 per cent. of these had to have more than one operation. The type of operation varied. Dr. Pease, using Dr. Chandler's method of fusion, obtained successful fusions in 85 per cent. of his cases. A small number of these required second operations. In Dr. Chandler's operation, it appears to be true that the tuberculous focus is collapsed, but is the disease completely eradicated by this procedure? Is it certain that the manipulation at operation does not cause dissemination of the tuberculosis? Is the situation in hip and in knee tuberculosis comparable? In how many cases is there a flare-up after successful fusion, no matter what the type of operation?

We believe the following criteria should be met in the treatment of tuberculosis of the hip:

1. An adequate period of preoperative care.
2. A successful fusion operation, which should provide:
   a. A high percentage of fusion in a relatively short period of time, in order to allow activity as early as possible;
   b. Fusion of the extremity in the optimum functional position;
   c. Avoidance of the tuberculous process as far as possible;
   d. Avoidance of the development of postoperative sinuses.

These criteria are best fulfilled in our hands by the Brittain operation. We intend to give the method a continued trial.

I agree with Dr. McCarroll that the invasion of the inferior aspect of the acetabulum occurs not infrequently, but it does not always involve so much of the ischium as to contra-indicate the Brittain operation. With traction, medial displacement of the distal fragment is not difficult. Complete circumferential division of the femoral periosteum is not necessary in order to displace the distal fragment medially; and displacement is necessary in the Brittain operation. If the ischium is involved, should osteotomy be performed as a compromise? This procedure necessitates rest during healing, and it may also in itself lead to fusion.

DR. H. D. MORRIS, NEW ORLEANS, LOUISIANA: Heretofore, on our Service at Charity Hospital and in the Louisiana State Crippled Children's work we have been reluctant to enter the area of tuberculous involvement and have confined ourselves, as far as possible, to extra-articular methods of fusion in tuberculous hips. However, the experience of Dr. Pease with the Chandler type of fusion should allay any hesitancy on the surgeon's part to combine intra-articular with the extra-articular technique, for certainly three failures in twenty-eight arthrodeses speak for the technical efficiency of this method. The ease and saving of time in a direct lateral approach to the involved hip should appeal to most operators, and the trochanteric graft offers an abundance of osteogenic material. Dr. Pease mentions one point, in the general treatment of tuberculous patients, which I would like to emphasize,—that is, the routine guinea-pig inoculation with the urine of all patients under active treatment every six months. Unless this is done, I am sure that many concomitant tuberculous kidneys, which exhibit no urinary symptoms, will be overlooked. The use of intrapelvic obturator neurectomy as a preliminary procedure to arthrodesis of the hip offers a new and unique attempt to prevent the occurrence of flexion and adduction contractures, which, in our own experience, have occurred all too frequently, even following excellent original hip surgery in which there was apparently satisfactory arthrodesis.

I think we are indebted to Dr. McCarroll for again stressing the extreme secondary manifestations, particularly the shortening which results after the prolonged fixation that is generally used in the treatment of tuberculous hips prior to fusion. It has been customary on our Service to use the same criteria as mentioned by Dr. McCarroll and to delay surgery until destruction has reached its maximum and an area of increased bone density about the tuberculous defect can be seen in the roentgenogram, indicating that the individual has shown some attempt to limit the tuberculous process. Stimulated by his observations, I rapidly reviewed five cases of adult tuberculous hips treated on our Service, in which cessation of growth had occurred, and I found that the maximum shortening was five and one-half inches and the average shortening three inches. I heartily agree that it behooves those of us who are doing work with crippled children to rationalize our initial treatment of tuberculosis of the hip in an attempt to prevent these extreme secondary changes, which are frequently as disabling as the primary disease.

I would like to show slides of two cases in which the Brittain type of arthrodesis was performed. In both instances, the medial portion of the graft was inserted into the ischium, which was definitely involved in the tuberculous process. The first patient was thirteen years of age at the time of arthrodesis and now, fourteen months following the operative procedure, has an excellent result with no evidence of involvement of the

graft. The second patient, in whom arthrodesis was performed at the age of four years, shows definite early extension of the tuberculous process into the graft. It is now seven months since the operation, and the outcome cannot be definitely determined at this time. These cases only re-emphasize the difficulties that Dr. McCarroll has outlined.

DR. JOSEPH S. BARR, BOSTON, MASSACHUSETTS: We have heard two excellent papers on the operative technique of fusion of the hip in childhood, when that joint is involved in a tuberculous process.

It is most important to consider not only the operative technique that should be employed, but also the best time for operation. In my opinion, too early operative interference does more to jeopardize a good operative result than do variations in technique.

In the acute or evolutionary phase of the disease process, there is slowly increasing destruction of the joint and adjacent bony structures, as shown by repeated roentgenographic examinations. Abscess formation occurs in about 50 per cent. of the cases, and in certain of these, draining sinuses develop. The general condition of the child reflects this situation, since he does not gain weight satisfactorily, muscle spasm is present about the hip, and blood studies usually show an increased monocyte-lymphocyte ratio. In other words, during this evolutionary phase, there is neither satisfactory local nor general resistance to the disease. Any attempt at fusion during this phase is doomed to a high risk of failure, for the active tuberculous process can destroy bone grafts about the hip joint as easily as it destroys the hip itself. During this phase of the disease, the treatment is, as H. O. Thomas said many years ago, "Rest, uninterrupted, continuous, and prolonged". The duration of this period of conservative treatment varies widely,—in some cases, a few months; in others, several years. When muscle spasm has subsided, when the child is in good general condition, when abscesses have regressed, and when repeated roentgenograms show no increased bone destruction, then we can safely operate with the expectation of obtaining solid fusion in about 70 per cent. of the cases at the first operation, and with the knowledge that we can increase that proportion of successful results to about 90 per cent. by several rather minor operations for the repair of pseudarthrosis in the bone graft.

I am in favor of a properly timed operation on the hip joint itself. The ischiofemoral arthrodesis has not been proved to yield better results.

DR. GERALD G. GILL, OAKLAND, CALIFORNIA: Dr. McCarroll is to be commended for re-emphasizing the occurrence of premature closure of the epiphyses about the knee in connection with tuberculosis of the hip in children. This is a serious, although not well-known, complication of this disease. In 1944, I reported fifteen cases of this condition. In every case, there was extreme decalcification of the bones of the affected extremity. This decalcification must be due to the long-continued inflammatory process in the hip and to disuse, consequent upon the long period of immobilization. Decalcification to this degree must radically change the physical structure of a cartilage plate, and make it more susceptible to trauma.

It is my belief that in decalcified bone, the cartilage plate probably exists as a fragile curtain between the two relatively fluid media. In addition, the decalcified bone is soft and bends easily. This bending may cause sufficient changes in the intramedullary pressure to rupture either the cartilage plate or the small blood vessels going into it. These changes will occur in the region of the greatest stretch, at or near its center. In three of the cases reported, there was diaphyseal fracture, followed by arrest of growth at both centers about the knee. The closure of both centers following the fracture of one bone indicates that trauma, not fracture, is the inciting cause of the arrest of growth. Therefore, unless it is found to be absolutely necessary, long periods of immobilization in the spica casts, prior to surgery, should be avoided before the cessation of growth, and arthrodesis should be performed as early as the patient's general condition permits. During the arthrodesis operation, at subsequent osteotomies, and during each change of cast, the limb should be handled with extreme care, particularly if the limb shows tenderness.

It is interesting to note that many years ago, Dr. Hibbs began to treat tuberculosis of the hip by early fusion, early weight-bearing in a walking cast, and early mobilization. Ten of the cases of premature closure, originally reported by me in 1944, were found from an analysis of 150 cases of tuberculosis of the hip in children, treated at the New York Orthopaedic Dispensary and Hospital. That such a small number of these complications occurred in such a large number of cases would seem to suggest that this is the treatment of choice.

The early recognition of premature closure is also of extreme importance, since it will allow early institution of those procedures necessary to prevent great inequality in length from the unopposed growth of the normal leg.

For this reason, I believe that, in every case of tuberculosis of the hip in children, frequent measurements of the long bones should be made by the use of scanograms. In those instances where it appears that there is extreme decalcification, markers should be placed in the shafts of each of the long bones and new scanograms should be taken at six-month intervals, so that the growth from each center may be accurately measured. This permits early decision as to the proper procedures necessary to give equalized length to the legs, satisfactory bodily proportions, and adequate final height.

DR. A. BRUCE GILL, PHILADELPHIA, PENNSYLVANIA: Forty years ago, when I began the practice of orthopaedic surgery, the accepted method of treating tuberculosis of the hip in children was by prolonged fixation in plaster casts. Observation over a period of years demonstrated that a frequent result of this method of treatment was a very marked shortening of the entire lower extremity,—often as great as four to six inches. We thus learned that prolonged encasement in plaster casts produced marked atrophy of skin, muscles, and bones, and prevented normal growth. The use of Buck's extension, enforced recumbency, prevention of gross movements of the hip joint, and exposure to sunshine has brought about happier results.

My own opinion is that we must consider tuberculosis of the hip as a general disease with a local manifestation, and that it can be arrested only through increasing the natural resistance of the child to this infection. Many of us have frequently observed that attempts to fuse a tuberculous hip in the acute stage of the disease do not result in fusion and an arrest of the disease process. On the other hand, the disease continues to spread and, not infrequently, the wound eventually breaks down and becomes infected with pyogenic microorganisms. It always appears particularly unreasonable to attempt to fuse a hip when the disease involves the ilium. How can prevention of motion by fusion cure the disease in a bone where there is normally no motion?

Fusion, in my opinion, is indicated only after the natural resistance of the child has gained mastery over the disease, and after the acute stage of the process has passed. I think the most suitable time for operation is after the child has reached his tenth year of age, provided the acute manifestations of the disease have disappeared. The object of fusion is not to cure tuberculosis of the hip, but to prevent local recurrence of the disease and to prevent or to correct deformity of flexion and adduction.

About twenty years ago I published a paper ("Pathological Dislocation of the Hip", *Southern Medical Journal*, **22**:207–212, 1929) in which it was demonstrated that intra-articular fusion can be accomplished in old cases of tuberculosis without danger of causing recurrence of the disease. These operations were done at a time when orthopaedic surgeons, for the most part, were fearful of operating upon a tuberculous joint.

I should like to emphasize again that operation upon a local focus will not of itself cure a general disease, and it will not cure the local manifestation of it, unless the resistance of the child becomes sufficiently developed to bring about an arrest or cure of the morbid process. We do not know of any short cut for the cure of tuberculosis. Individuals affected by this disease must, throughout all their lives, maintain their bodily resistance at a high level to prevent local manifestations of the disease in various parts of the body.

DR. C. N. PEASE, CHICAGO, ILLINOIS (closing): I did not come here to discuss the Brittain operation. I came here to show what I believe is the best approach to an active tuberculosis in the hip joint. I think the number of cases shown here this morning bear out my point. I had a good many more slides to show, several of which illustrate eradication of the active tuberculous areas.

In reply to Dr. Perlman, the knee joint is just as much a weight-bearing joint as the hip joint, yet there is no hesitancy on the part of any orthopaedic surgeon about fusing a tuberculous knee joint. It is true that you may run into active disease and that you may expect drainage, but not any more so than in a tuberculous knee. We feel that we give our patients adequate preoperative care before starting this procedure. We have had none go into acute surgical shock. I remember no case where a blood transfusion was performed at the time of operation. This operation is simple; it takes about thirty minutes. The obturator-nerve section is done as a preliminary and takes only ten or fifteen minutes.

I think Dr. Morris and Dr. Barr spoke of waiting until the tuberculous process became stationary. If you wait for that, before you do your fusion, you will wait a long time. Dr. McCarroll showed that some of these patients had been five or ten years in plaster—so long that shortening of the leg from five to seven inches had occurred—and still the process was active. We get our children into the best possible condition, with the blood count up and the sedimentation rate down; when they reach this point, we do our surgery. One young boy had had the disease for five years and was treated elsewhere by so-called "corrective measures". We felt that sufficient time had been spent on this type of therapy. His condition was as good as it was going to be. He was operated upon one week after admission to the Hospital. He later became a basketball player and a baseball pitcher and was offered an athletic scholarship at a small Illinois college. It you wait until roentgenograms show a decrease in tuberculous activity, you will wait a long time; and in many of these cases, further destruction takes place.

DR. H. RELTON MCCARROLL (closing): In answer to Dr. Gill, I realize that none of the work presented is original. Most of these procedures and the types of arthrodesis presented have been done over and over again. We know that many years ago Dr. Hibbs discontinued prolonged plaster immobilization of tuberculous hips, because of the marked shortening which resulted in the extremities, but most of us are stubborn enough to believe something much more readily after we have had an opportunity to try it ourselves.

IDIOPATHIC SCOLIOSIS

A Method of Correction *

BY GORONWY E. THOMAS, M.CH. (ORTH.), F.R.C.S. (EDIN.), LIVERPOOL, ENGLAND

Idiopathic scoliosis is a most discouraging condition to treat. Its etiology is so vague and its course so variable that the prognosis in any given case becomes difficult or impossible to determine. In possibly the majority of patients, the degree of deformity will be limited by a spontaneous arrest of the process. In others, the curvature will increase during the period of growth and will produce not only intractable deformity, but also a deterioration in general health.

It can be assumed, therefore, that any patient allowed to go untreated may become worse, and that efforts should be directed toward preventing an increase in the deformity and toward correcting, as far as possible, the condition which is already present.

DISADVANTAGES OF PRESENT METHODS

Many methods and devices have been suggested for the correction of the deformity. Since most of these have failed, there is as yet no satisfactory method of treatment. The application of the commonly employed corrective plaster jackets tends to be exhausting to the patient and laborious for the surgeon. Moreover, the results, even after long periods, are too uncertain a reward for the labor and endurance involved. Treatment by turnbuckle jackets, a method revived in the last few years, has the added disadvantage of tending to produce or to accentuate a secondary curvature. In attempting to correct the deformity, the disproportion between the effort involved and the response obtained has formed the basis of the statement once made that "the treatment of scoliosis is a perpetual lesson in humility".

It was in an attempt to reduce this disproportion that the method here described was developed. In this presentation, the author will confine himself strictly to the correction of idiopathic scoliosis in children. The equally difficult problem of maintaining the correction does not enter into the province of the present paper.

THE IMPORTANCE OF THE ROTATIONAL ELEMENT IN THE DEFORMITY

The deformity is complex, consisting of a lateral deviation of the spine with rotation of the vertebrae. Opinion is still divided on the questions of whether the lateral deviation or the rotation is the initial deformity, and whether these two changes may be independent of each other or the natural concomitants of some underlying cause. However, it is generally assumed that rotation is secondary to lateral deviation. The latter element is always accompanied by some rotation except in the very mildest grades; while in the more severe curvatures, rotation is pronounced. Moreover, in some instances, notably the so-called "razor backs", rotation is the main element in the deformity.

No constant ratio exists between these two components, but the rotational defect is the more resistant to correction. In fact, it is doubtful whether derotation can be effected in any but the mildest curvatures, and this fact is borne out in the results in the cases to be described.

Resistance to correction is due mainly to structural changes in the vertebrae,—changes indicated by the appearance of wedging of the vertebral bodies, as seen in the anteroposterior roentgenograms (Fig. 1). On purely mechanical grounds, this wedging may explain the resistance to correction of the lateral deviation, but it does not explain the

* Based on a paper read at the Annual Meeting of The British Orthopaedic Association, Oxford, England, January 3, 1941.

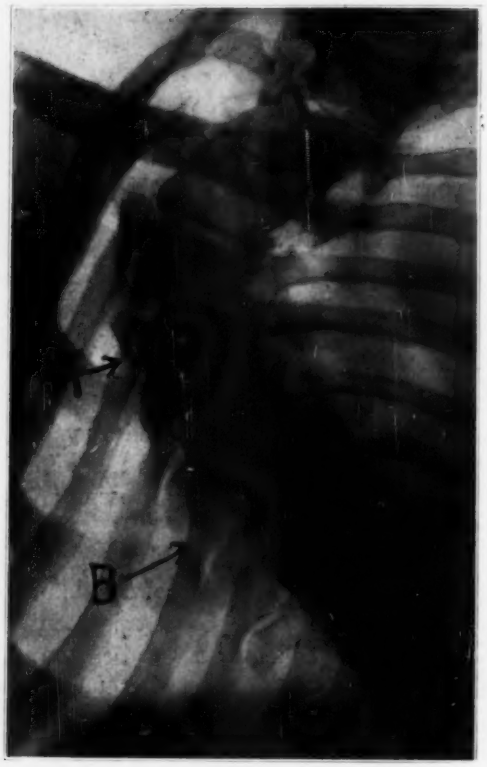

FIG. 1

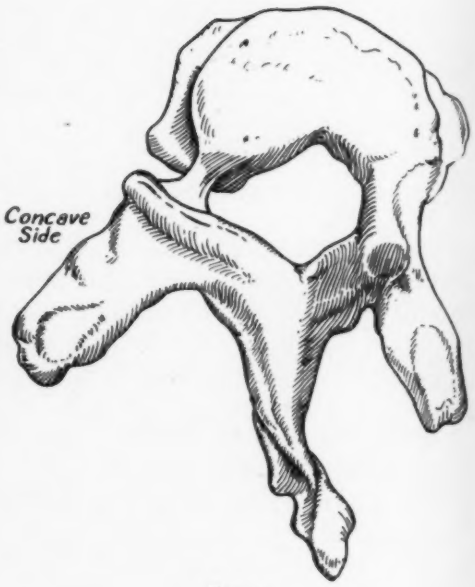

FIG. 2

Fig. 1: Showing the typical appearance of wedging at *A*, and also changes indicating rotation of bodies as a whole. At level *B* there is no rotation, and the outlines of the pedicles are disposed symmetrically. At level *A* there is rotation; and the outline of the pedicle is visible on the convex side only, and is displaced medially relative to the lateral border of the vertebral body.

Fig. 2: A vertebra from the middle of a curve, as seen from above, showing atrophy of the pedicle on the concave side. (*According to Broca.*)

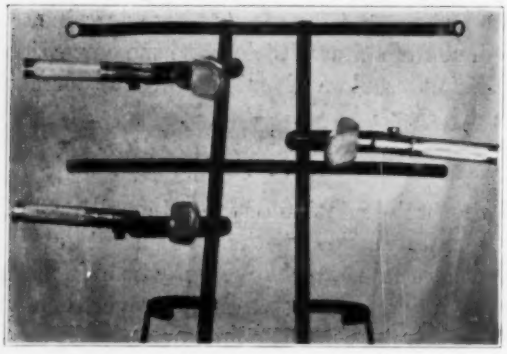

FIG. 3

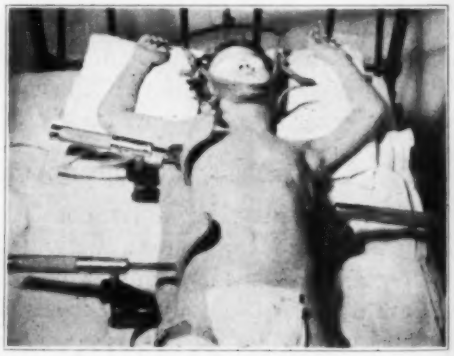

FIG. 4

greater resistance to correction of the rotation. Rotation in itself is a complicated deformity, and its precise nature cannot be learned from a roentgenogram. It comprises two elements,—the rotation of the vertebrae as a whole, and the structural distortion of the various parts of each individual vertebra.

It is assumed that, as lateral deviation develops, each vertebra in the affected segment rotates on a vertical axis situated somewhere behind its spinous process. The total rotary displacement in the spine is recognized in roentgenograms as a general asymmetry of the shadows of the pedicles in relation to their corresponding vertebral bodies. Normally, the outlines of each pair of pedicles are seen roentgenographically to be disposed symmetrically toward the lateral borders of each vertebral body (Fig. 1, *B*). If the vertebral bodies rotate,

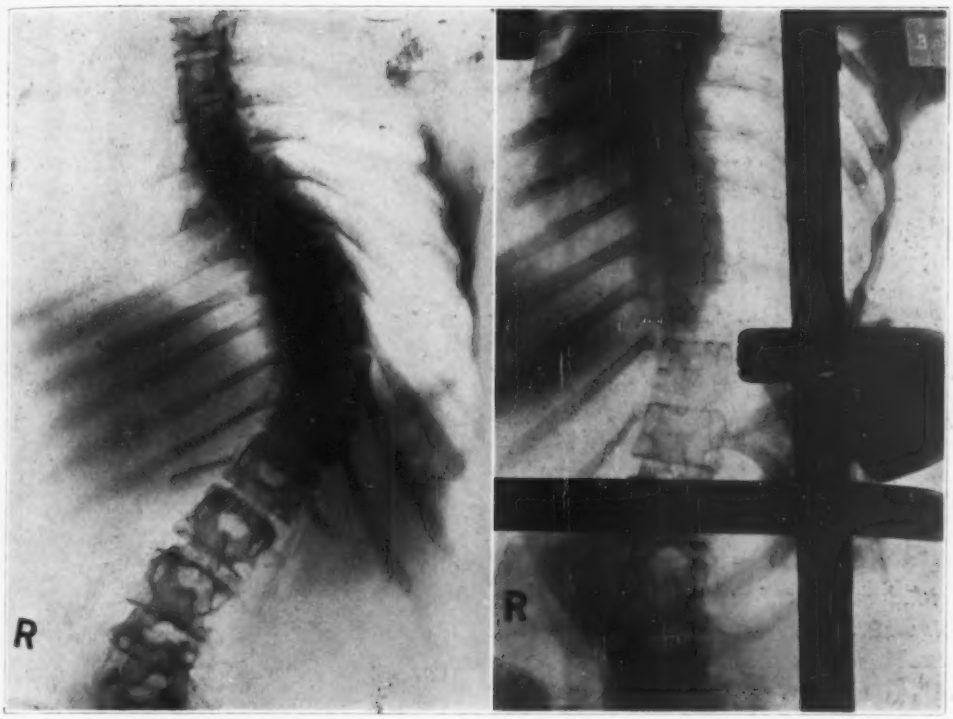

FIG. 5-A FIG. 5-B

Fig. 5-A: Case 1. E. M. B., a girl, aged twelve. Moderate wedging and rotation.
Fig. 5-B: After correction, wedging is more obvious and derotation has occurred.

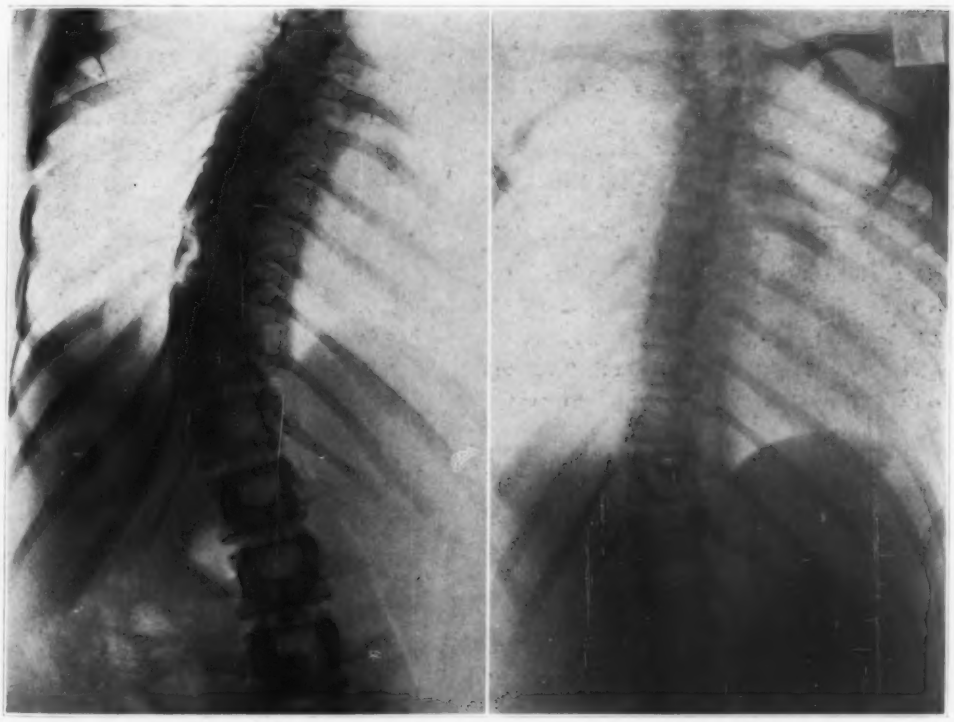

FIG. 6-A FIG. 6-B

Fig. 6-A: Case 2. M. N., a girl, aged fourteen. Mild degree of wedging, but severe rotation.
Fig. 6-B: Roentgenogram, taken after corrective forces have been removed, shows improvement of lateral deviation, but only slight improvement of rotation.

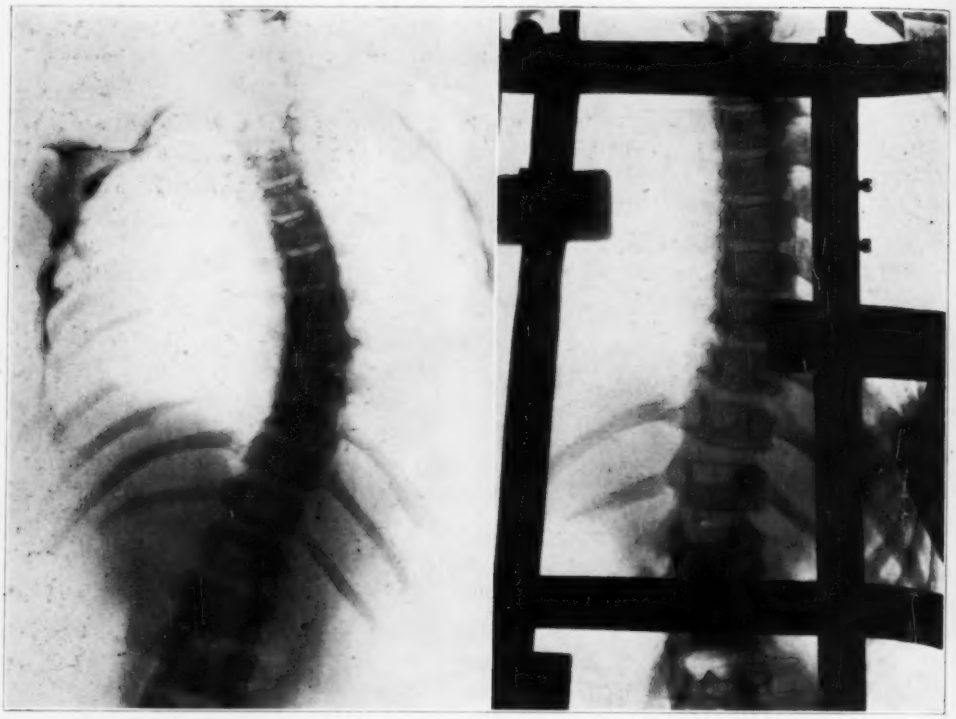

FIG. 7-A FIG. 7-B

Fig. 7-A: Case 3. W. B., a boy, aged twelve. Mild degree of wedging and very little rotation.
Fig. 7-B: After correction of lateral deviation, rotation actually increased.

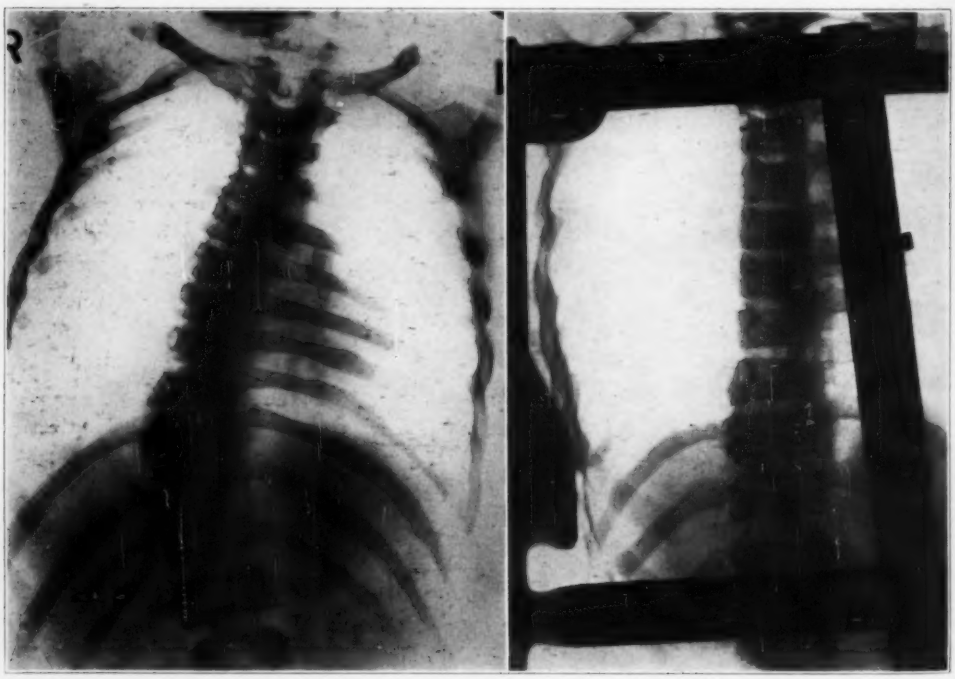

FIG. 8-A FIG. 8-B

Fig. 8-A: Case 4. E. D., a girl, aged thirteen. Mild degree of wedging and rotation.
Fig. 8-B: Showing full correction of both.

the shadows on the convex side of the deformity will be displaced medially away from the lateral borders of the bodies on that side (Fig. 1, *A*), while those on the concave side will

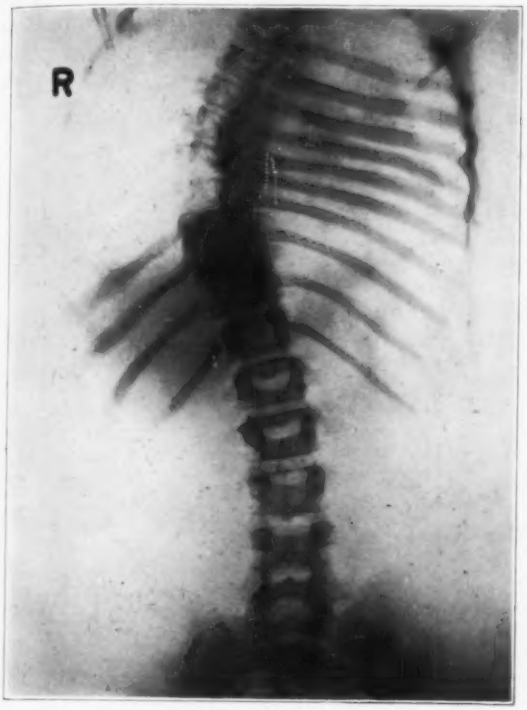

FIG. 9-A

FIG. 9-B

Fig. 9-A: Case 5. N. R., a girl, aged ten. Moderate wedging and severe rotation.

Fig. 9-B: Lateral deviation is much improved, but rotation remains the same.

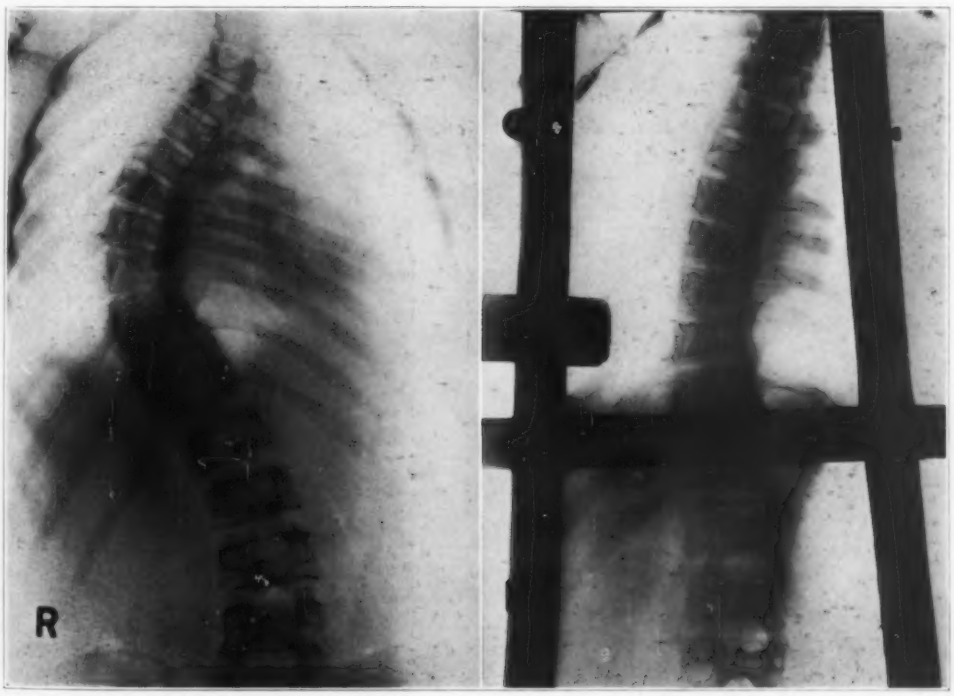

FIG. 10-A FIG. 10-B

Fig. 10-A: Case 6. H. S., a girl, aged thirteen. Severe wedging and rotation.
Fig. 10-B: Rotation unaffected, although lateral deviation has improved.

become less distinct and in severe cases may disappear entirely as a displacement in the same direction takes the pedicles away from roentgenographic view.

The second element in rotation, that of structural distortion of the various parts of an individual vertebra, involves particularly the posterior arch. Figure 2 depicts a vertebra taken from the middle of a mild curvature. A salient feature of this distortion is atrophy of the pedicle on the side of the concavity. If the vertebrae are considered in relation to

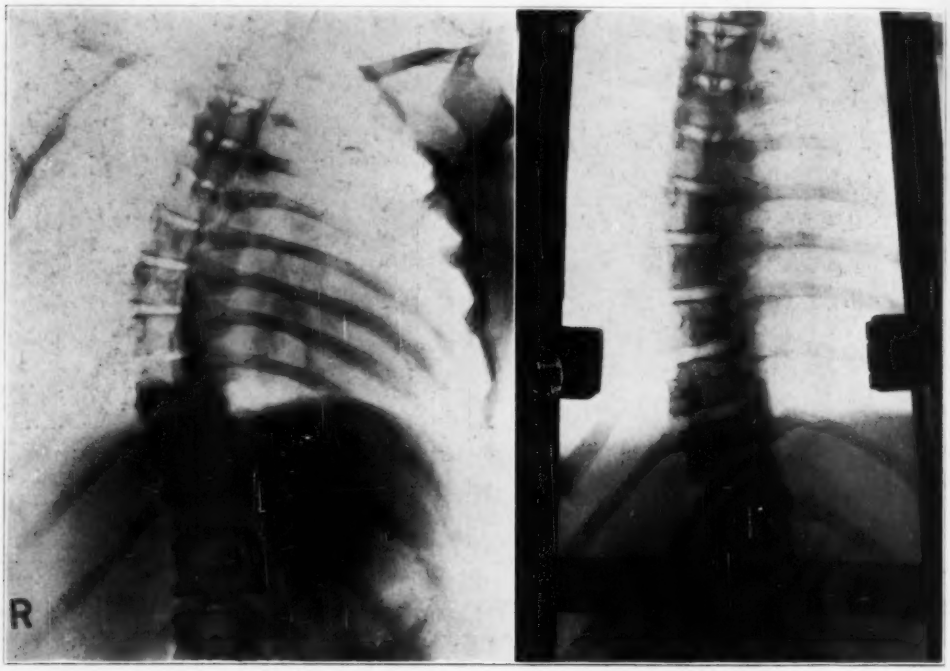

FIG. 11-A FIG. 11-B

Fig. 11-A: Case 7. B. W., a girl, aged fourteen. Mild wedging and moderate rotation.

Fig. 11-B: Improvement in lateral deviation, but rotation is unaffected. Note that corrective pad on right is too low.

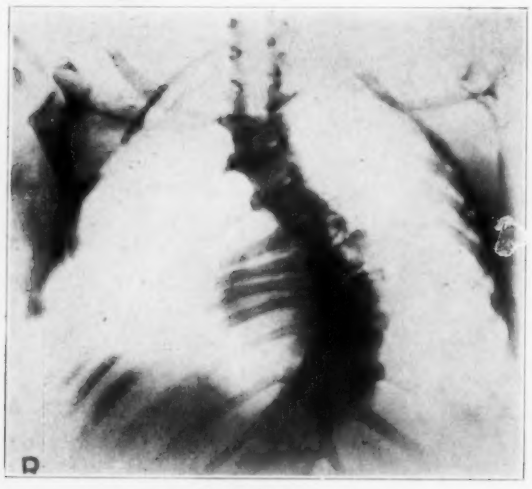

FIG. 12-A FIG. 12-B

Fig. 12-A: Case 8. T. C., a girl, aged thirteen. Extreme wedging, rotation, and rib deformity.
Fig. 12-B: Slight improvement in lateral deviation and rotation.

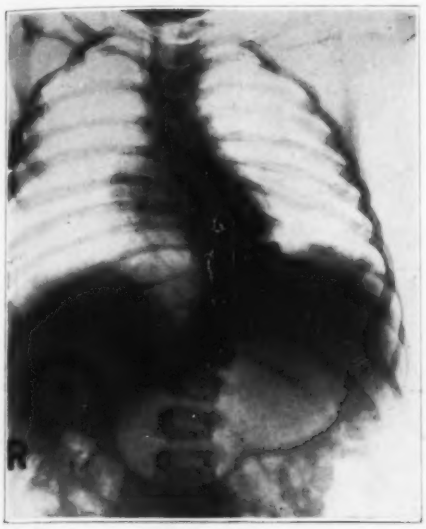

FIG. 13-A

Fig. 13-A: Case 9. J. K., a girl, aged six. Even at this early age it was not possible to achieve full correction.

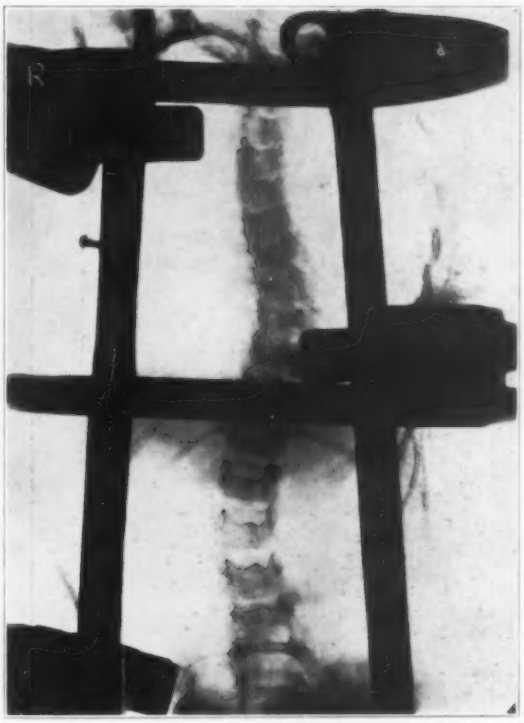

Fig. 13-B: The lateral deviation is improved, but rotation, which was severe, is only slightly reduced.

FIG. 13-B

one another, it will be seen that the articular facets on the concave side are thrown out of alignment with those on the convex side, with consequent locking of the vertebrae in their rotated position.

While realizing that contracture of soft parts is a factor preventing correction, the writer believes that the most formidable obstacle consists in these complex twists of the arch. These changes are not fully revealed roentgenographically, and we have no means of measuring their extent, but wedging of the centra is to be regarded as an indication of their presence.

On examination of the patient, rotation is generally less apparent than lateral deviation, and fortunately the latter component can be reduced greatly by treatment.

METHOD OF CORRECTION

The method to be described consists in a combination of recumbency, traction, and lateral pressure.

1. *Recumbency:* Since the upright posture favors the progress of the deformity, recumbency is an important factor in its correction. The influence of gravitation is eliminated by placing the patient on a Thomas spinal frame, fitted with a head piece.

2. *Traction in the Axis of the Spine:* Although the usefulness of intermittent traction during the application of plaster jackets in suspension has long been recognized, the value of continuous traction in the treatment of scoliosis has been underestimated. Indeed Lovett [1] believed that, when traction is exerted on the spine, the tension so produced prevents lateral pressure from exerting any corrective influence. The cases to be described do not support this belief. Longitudinal traction is exerted on the spine by fixing the lower extremities by extension strapping to the foot pieces of the frame, and by applying weight traction to the head through a Sayre halter.

3. *Lateral Pressure:* In order to exert lateral pressure, special appliances have been devised, and with the employment of these the amount, direction, and site of the thrust

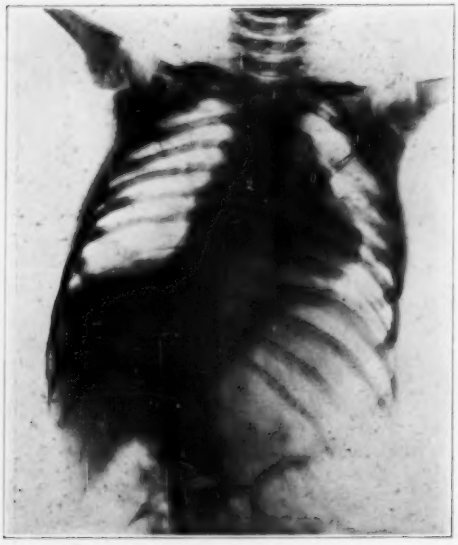

FIG. 14-A

Fig. 14-A: Case 10. G. G., a boy, aged five. Another example of idiopathic scoliosis at an early age.

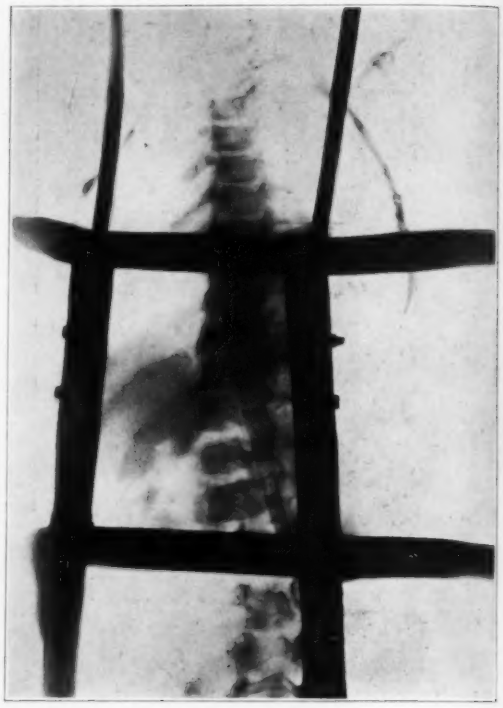

Fig. 14-B: Good correction, but rotation is still severe.

FIG. 14-B

can be controlled. These screw pressure pads (Fig. 3) are attached to the horizontal bars of the Thomas frame. One pad is applied to the chest wall, opposite the point of maximum curvature. Two others are applied on the opposite side,—one against the pelvis and the other against the chest wall at the upper extremity of the curve, usually near the axilla. Counterpressure will thus prevent the production or accentuation of secondary curves.

PROCEDURE

The patient is put on the frame for three or four days, in order that he may become accustomed to it. Fixed extensions are then applied to the legs, and weight traction to the head, commencing with about ten pounds. The head of the bed is raised two feet. After two days the pressure pads are applied and are brought to bear gently on the trunk (Fig. 4).

The weights are increased by about one pound daily, and, although a maximum of about twenty-five pounds for the younger patients and thirty pounds for the older patients is aimed for, the comfort of the patient is the governing factor in determining the amount of weight used. The screws are tightened twice daily. The amount of pressure exerted by the pads is a matter for judgment, but it should never be sufficient to produce discomfort. Roentgenograms are taken every two weeks while the correcting forces are in operation.

The nursing is simple. Release of the screws and weights once daily for skin toilet suffices.

RESULTS

Fifteen cases of idiopathic scoliosis have been treated by this method, and the results are shown in the form of paired roentgenograms, taken before and after correction. Of these fifteen patients, three benefited little from the treatment for one or the other of the following reasons:

1. In one (Figs. 17-A and 17-B) the curve was too high in the thoracic region. A pad could not be applied opposite the point of maximum curvature, and counterpressure was impracticable.

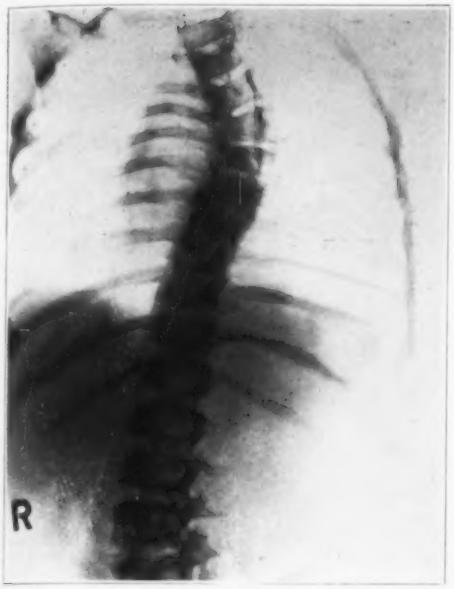

FIG. 15-A

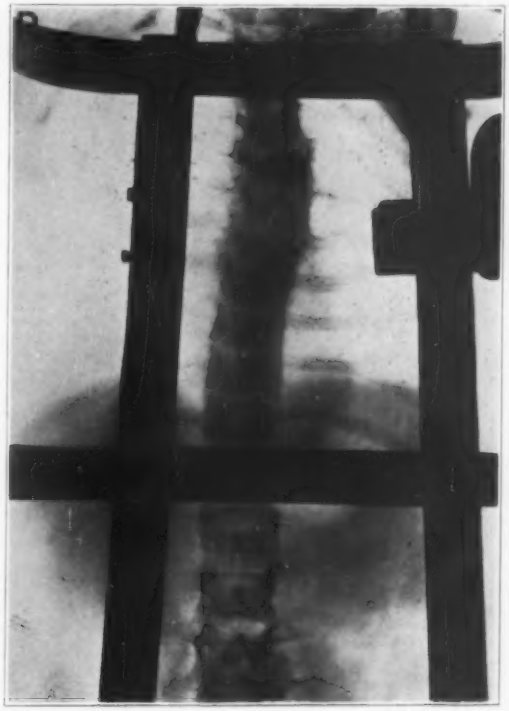

FIG. 15-B

Fig. 15-A: Case 11. P. N., a boy, aged six. A fairly acute curve in the upper thoracic region, with severe wedging of the fifth thoracic vertebra.

Fig. 15-B: Good correction of lateral deviation, but rotation is still present.

FIG. 16-A

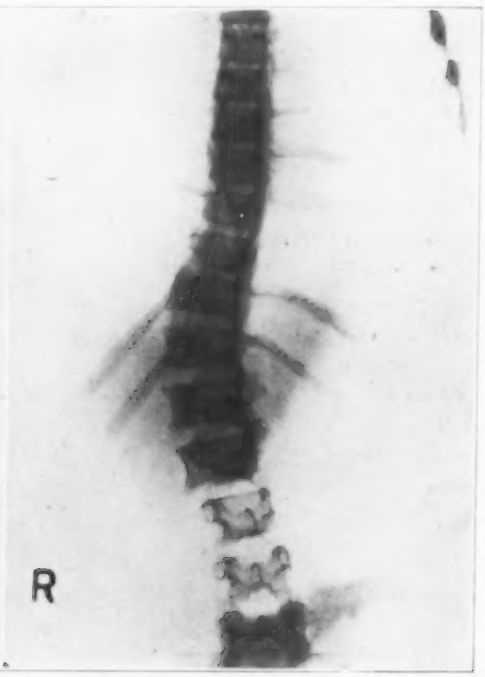

FIG. 16-B

Fig. 16-A: Case 12. J. C., a girl, aged eight. A sharp thoracolumbar curve with severe rotation.

Fig. 16-B: Roentgenogram, taken without corrective forces acting, shows good correction, but rotation is still severe.

2. In the other two (Figs. 18-A, 18-B, 19-A, and 19-B) it was clear that the severity of the curvature would not allow full correction.

FIG. 17-A

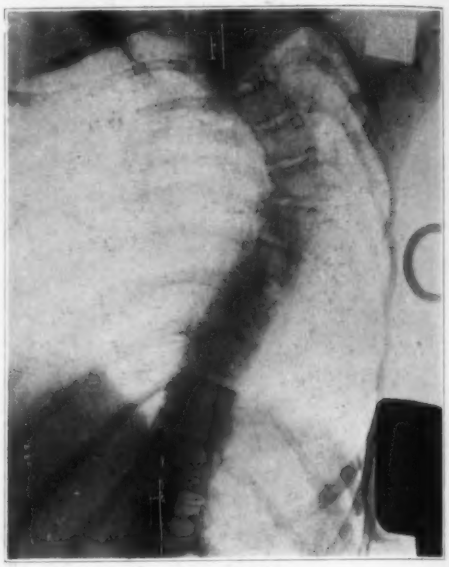

FIG. 17-B

Case 13. B. G., a girl, aged fourteen. This case was unsuitable for method, because the curve is too high and counterpressure is not practicable.

FIG. 18-A

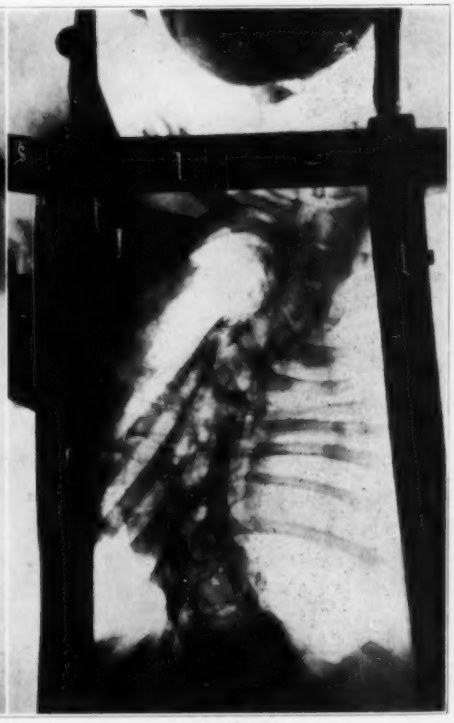

FIG. 18-B

Fig. 18-A: Case 14. E. M., a girl, aged fourteen. An extreme type of deformity with severe structural changes.

Fig. 18-B: In spite of this, an appreciable amount of correction has been obtained.

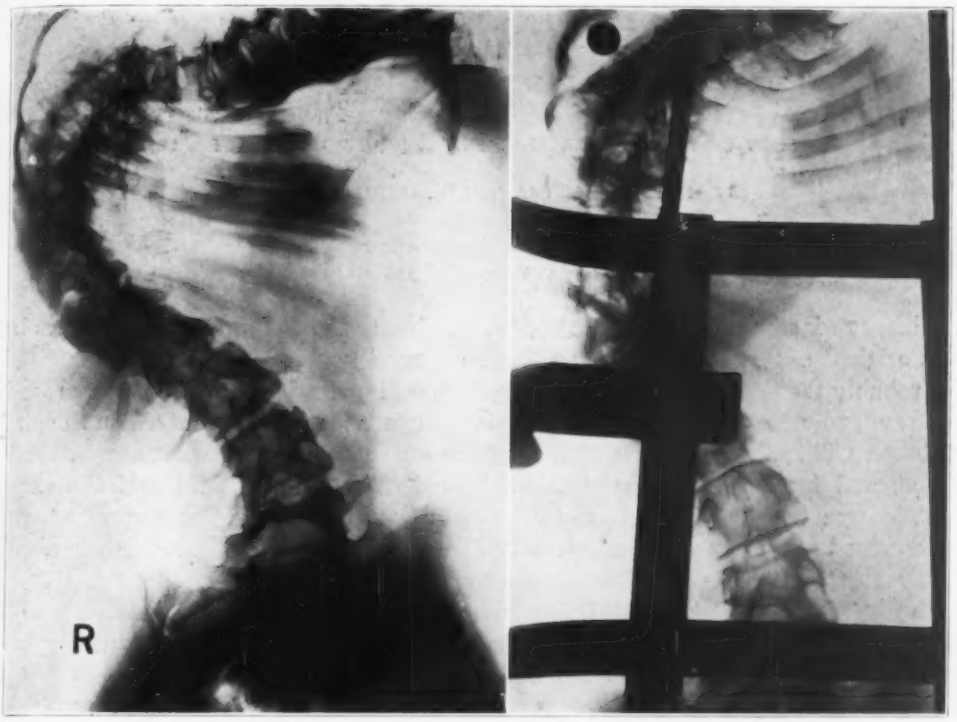

FIG. 19-A FIG. 19-B

Fig. 19-A: Case 15. M. C., a girl, aged thirteen. This case was unsuitable for method, because curve is too severe.

Fig. 19-B: Slight amount of correction has been obtained.

It is also obvious that a lumbar curve is not amenable to this form of treatment, because of the absence of any structures through which pressure can be applied effectively.

Progress: It was interesting to observe that in every case the maximum correction obtainable was secured within eight weeks, and that no matter how much the forces were increased, or how long they were in operation after this period, no further improvement could be obtained.

Complications: In the fifteen patients treated, there were complications of a minor character in but two. In one a sore developed under a pressure pad, and healing ensued after complete release of pressure for three weeks. Following this, pressure was re-applied more gradually. In the other patient, a slight palsy of one arm was relieved by release of the pressure, which was later re-applied at a slightly lower level. There were no complications due to traction by the Sayre halter.

SUMMARY

The results from this method of correction of idiopathic scoliosis show very encouraging improvement over those obtained by other methods.

From the study of these patients, the writer has not been able to draw any conclusions as to why some cases of curvature are more amenable to correction than others of the same apparent severity, at the same age.

Rotation was a prominent feature in all, but the amount of lateral correction obtained did not appear to bear any constant relationship to it. This rotation was corrected in only two cases (Figs. 5-B and 8-B); in all the others, it persisted or even increased.

1. Lovett, R. W.: Lateral Curvature of the Spine and Round Shoulders. Philadelphia, P. Blakiston's Son and Co., 1907.

OSTEOID OSTEOMA

Review of the Literature and Report of Thirty Cases *

BY MARY S. SHERMAN, M.D., CHICAGO, ILLINOIS

From the University of Chicago, Department of Surgery, Division of Orthopaedic Surgery, Chicago

Although instances of osteoid osteoma had been reported under other names before Jaffe's original paper, the lesion had not been generally recognized.

Probably the first description of the pathological picture of this disorder was made by Bergstrand, who, in 1930, reported two cases,—one in a metatarsal, and one in the phalanx of a finger. Clinically, both were thought to be osteogenic sarcoma. The metatarsal was resected, and the finger was amputated. The detailed clinical data and the excellent photomicrographs leave no doubt as to the identity of the lesions. Bergstrand interpreted them as rare benign osteoblastic lesions and, because he thought them neither neoplastic nor inflammatory in nature, he attributed them to embryonal rests.

In 1934, Milch described this lesion and recognized the similarity of his cases to those of Bergstrand. He concluded that he was dealing with a benign osteoblastic tumor, forming osteoid tissue, and recommended surgical excision.

The lesion received little attention, however, until 1935, when Jaffe published an account of Milch's three cases and also of two more, with a careful analysis of their individual clinical and pathological characteristics. To Jaffe is due the credit for establishing this lesion as a distinct entity. Marziani's paper, in 1936, presented one more case. Rinonapoli added three cases in a report in 1937. In 1938, seven cases were reported by Mondolfo, who interpreted them as chronic osteomyelitis. By 1940, Jaffe and Lichtenstein had added twenty-eight more cases. Since then reports of many cases have been published [1, 2, 6, 7, 8, 9, 11, 12, 13, 14, 18, 22, 23, 24, 27, 29, 30, 32, 34, 35, 36, 37, 39, 40]. The last comprehensive report was made by Jaffe in 1945, when he presented his total of sixty-two cases and gave a general review of the subject, including a restatement of the argument as to whether or not the osteoid osteoma is a separate lesion.

As one would expect, in the older literature, reports of osteoid osteomata are presented as examples of other lesions. In 1929, Phemister described under the term "chronic fibrous osteomyelitis" several cases, among which can be distinguished one that is unquestionably an osteoid osteoma. Two more instances of this lesion were reported by Compere, in 1932, as *Streptococcus viridans* osteomyelitis. All three of these cases are included in the present series. In 1935, Zanoli described a case which he considered to represent an incomplete repair of a post-traumatic aseptic necrosis. From the excellent illustrations, it is easily identified as an osteoid osteoma of the capitate.

In addition, there are several reports, such as those of Heine, Hitzrot, Raspall and Llort, Thoma, and Weeden and Oliva, which are suggestive of osteoid osteoma, but which do not include sufficient data to permit definite diagnoses.

CLINICAL PICTURE

The clinical features of osteoid osteoma are by now well known. The disorder is much more common in the male. Of 127 cases in which the sex was reported, eighty-seven were males; of the thirty additional patients here reported, twenty are males. Thus, the ratio of males to females is greater than two to one. Only one case has been reported in a negro [18].

It has been said by Jaffe that the lesion has a predilection for adolescents and young

* This work was aided by a grant from the Douglas Smith Foundation.

TABLE I

AGE INCIDENCE

Age (*Years*)	Reported Cases	Present Series	Total
1–5	8	1	9
6–10	9	9	18
11–15	30	8	38
16–20	35	5	40
21–25	24	2	26
26–30	14	2	16
31–35	3	2	5
Over 35	2	1	3
Not stated	3		3
Totals	128	30	158

adults. Indeed, over half of the patients already reported are between ten and twenty years old. As may be seen in Table I, the age incidence in the present series is slightly different, with over half of the patients between the ages of five and fifteen years. The youngest patient in our series was three years old and the eldest was fifty-one.

In Table II, the locations of the previously reported lesions are compared with those of the present series. It will be seen that, in general, the locations of the lesions in the

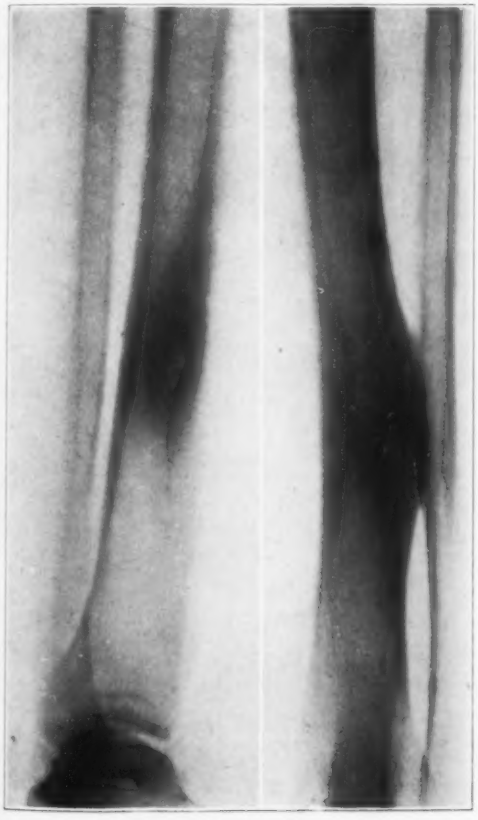

FIG. 1-A

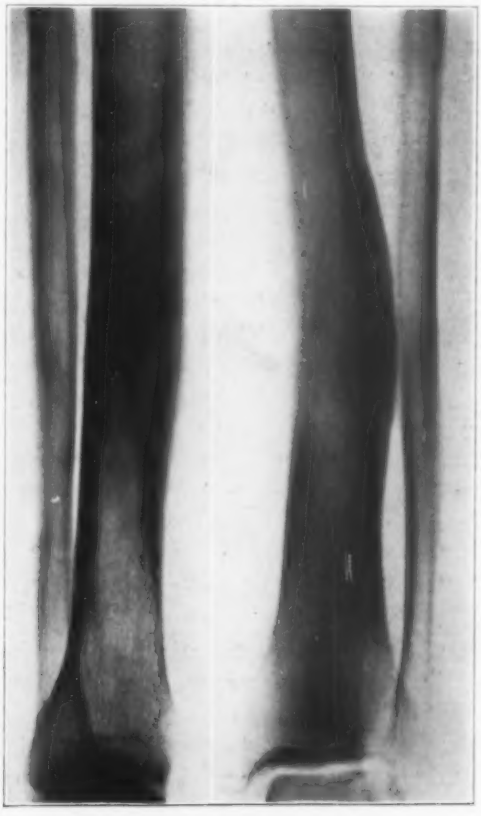

FIG. 1-B

Fig. 1-A: Initial roentgenograms of the left tibia, showing a densely sclerotic area with an oval radiolucent center.

Fig. 1-B: Roentgenograms twenty-four years later, showing persistence of sclerosis, but no demonstrable nidus.

TABLE II

LOCATION OF LESION

Bone	Cases in the Literature	Present Series	Total
Tibia	33	4	37
Femur	24	7	31
Astragalus	12	1	13
Vertebrae	11	7	18
Humerus	9	1	10
Fibula	7		7
Toes	6	3	9
Fingers	5	4	9
Os calcis	4		4
Radius	3	1	4
Ulna	3		3
Carpal navicular	3		3
Ilium	2	1	3
Patella	1		1
Pubis		1	1
Tarsal navicular	1		1
Hamate	1		1
Capitate	1		1
Ankle	1		1
Rib	1		1
Totals	128	30	158

present series correspond well with those given in the literature. The only noteworthy exception is that almost 25 per cent. of the lesions of our series were lesions of the spine, which were as numerous as those in any other category,—probably because of our group's special interest in this particular disorder. A separate paper on these cases is being published elsewhere [15]. In any given bone, the lesion may be entirely in cancellous bone, beneath or in the cortex, or even in subperiosteal tissue.

All the patients in this series sought medical advice because of pain. Their stories are remarkably similar. The pain, which at first was rather vague, mild, and intermittent, gradually grew in severity and constancy and localized to a very small area. Twenty-four of the thirty patients volunteered the information that the pain was most severe at night, and often prevented sleep or awakened them. Three patients had had symptoms for only two months; twenty-one for from six months to two years; and the remaining six, for more than two years. One patient had had unremitting pain for six years. When the lesion is in the spine, there may be associated root pain and even symptoms of cord compression [15, 25, 28, 34].

The chief physical finding is that of tenderness, which usually can be definitely localized, even by the very young patient, and which may be exquisite. If the lesion has been present long enough, there is usually palpable thickening of the bone. Lesions in bones with little soft-tissue covering may be accompanied by swelling, but this area is rarely warm and never red. If the site of the lesion is near a joint, motion of that joint is often limited and painful. Occasionally there is increased fluid in the joint, and the findings may be such as to simulate a primary arthritis [36]. Involvement of the lower extremity usually produces a limp and atrophy of the muscles. In the spine, an osteoid osteoma produces all the signs of acute localized back pain, including muscle spasm, secondary scoliosis, and pelvic tilt.

There are no systemic complaints or findings. The patients are afebrile and have normal blood counts.

Roentgenographic examination of a mature lesion reveals a characteristic picture. The active nidus is usually a small round or oval area of reduced density. Often one can see within it a small dense shadow, which represents ossification of the central portion. About this nidus, a thick, dense shadow of sclerotic regional bone is almost always present. If the lesion is at or in the cortex, the regional hypertrophy, especially along the periosteal surface, is much greater. The circumference of the shaft may be so greatly increased, and the bone may be so sclerotic, that the nidus is difficult to demonstrate by roentgenogram.

The response to the treatment of osteoid osteoma is most satisfactory, for immediate and permanent relief of symptoms follows excision of the nidus. It is not necessary to remove all of the hypertrophic regional bone, which may gradually resorb, particularly in children; but, if the nidus is not excised completely, persistence or recurrence of symptoms is the rule.

Since only eight of 155 patients were older than thirty, one is justified in assuming that the lesion may heal spontaneously.

In this connection, the history of a man who is not included in this series is of interest. In 1916, when he was eighteen years old, he consulted Dr. D. B. Phemister because of pain, tenderness, and swelling, which had been present in the lower portion of the left tibia for one and one-half years. Roentgenograms (Fig. 1-A) showed a lesion which we would now have no hesitancy in calling an osteoid osteoma. Surgery was refused by the patient. Gradually the pain and tenderness decreased; and, by 1921, seven years after their onset, the symptoms had disappeared and did not return. In 1940, twenty-four years after his initial visit, the patient was examined again. Swelling was still present, but there was neither pain nor tenderness. Roentgenograms (Fig. 1-B) showed persistent sclerosis and thickening of the cortex, but there was no sign of the nidus. A similarly suggestive case is included in the report made by Moberg.

FIG. 2-A

Case 1. Initial roentgenogram, showing a large radiolucent lesion at the juncture of pubis and ischium. As yet, very little reaction of surrounding bone is evident.

Most of the general characteristics are illustrated in the following typical case reports.

CASE 1. E. G., a sixteen-year-old girl, was first seen in March 1944, complaining of pain in her right leg, which had begun one year before. At first mild, generalized, and intermittent, the pain had gradually become more severe and had centered in the knee and thigh. For two weeks before her admission, she had been unable to walk and the pain had kept her awake at night. There was a vague history of a bruise on the right hip a month before symptoms began. There had been no fever or infectious diseases.

Physical examination was normal except for pain in the hip with extremes of abduction and adduction, and tenderness over the pubis, which could be elicited by rectal examination. The results of routine laboratory examinations were all within normal limits.

Roentgenograms of the pelvis showed a radiolucent lesion at the juncture of the right pubis and ischium (Fig. 2-A). There was relatively little sclerosis of the regional bone. The preoperative diagnosis was enchondroma.

At operation, a bulging mass of hemorrhagic fibrous tissue, about 2.5 centimeters long, was removed; and its bed was curetted. There was primary healing of the wound, and tissue cultures showed no growth.

The patient was immediately relieved of pain, and returned to normal activity as soon as the wound had healed. When last seen, four months later, she was still asymptomatic.

Sections of the material removed at operation showed a very immature lesion (Fig. 2-B). The vascular fibrous-tissue stroma was extremely cellular, and there were great numbers of multinucleated giant cells. The osteoid tissue was prominent; but, instead of being deposited in irregular masses, it was arranged in

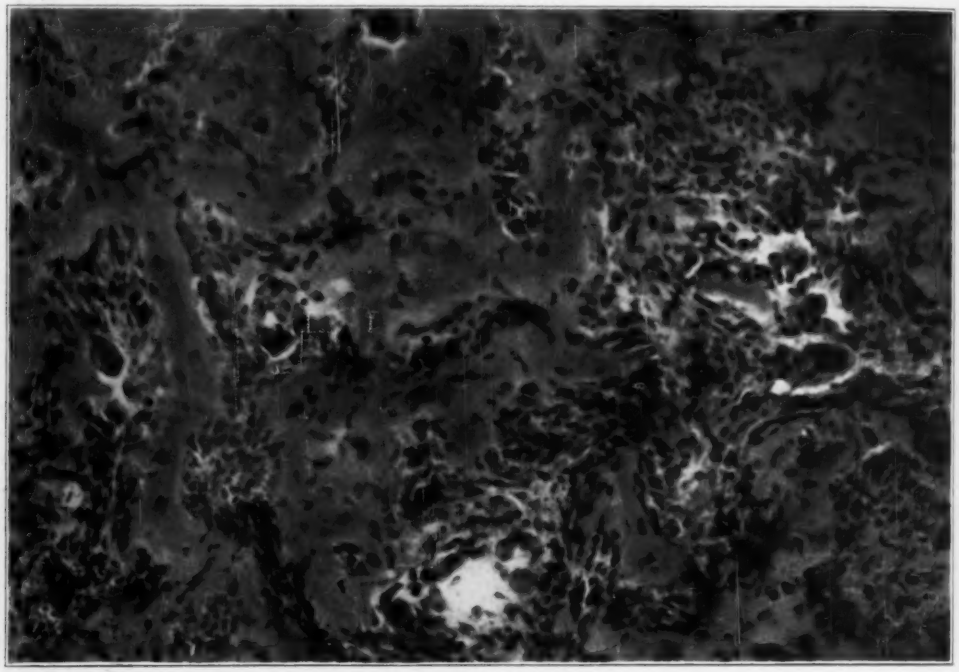

FIG. 2-B

Photomicrograph (× 200). At the center of the lesion there is cellular fibrous tissue, containing giant cells and many well-formed irregular trabeculae of osteoid tissue.

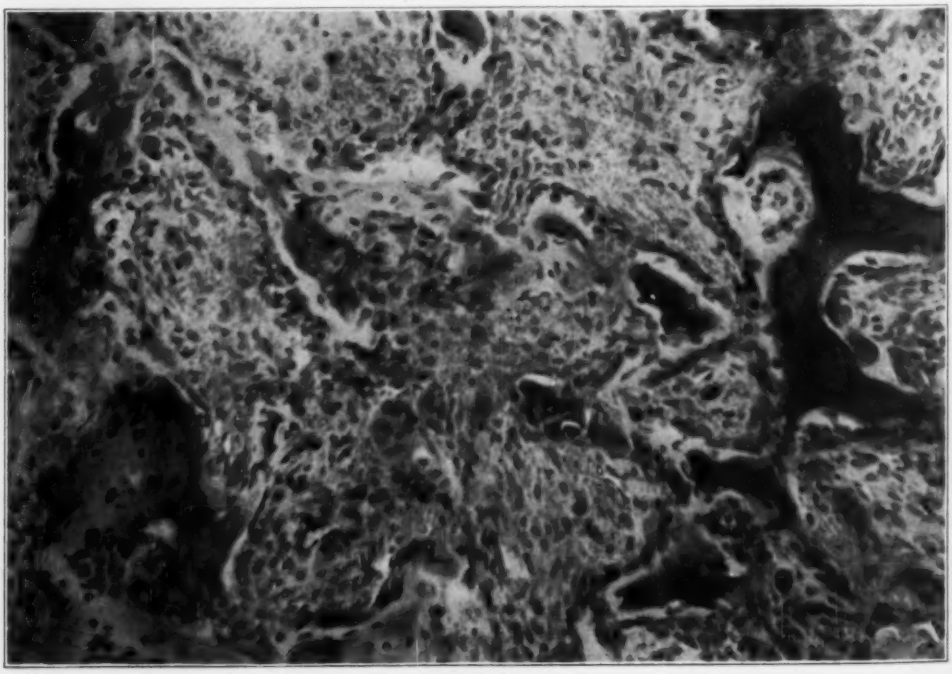

FIG. 2-C

Photomicrograph (× 200). Nearer the periphery, there is calcification of some of the trabeculae.

many delicate, well-formed, interlacing trabeculae. Most of these showed no calcification at all, but in a few places the trabeculae had become bone (Fig. 2-C).

While this lesion was unquestionably an osteoid osteoma, it showed much more of a pattern than is usually the case.

CASE 2. J. D., a sixteen-year-old male, was seen in June 1940, complaining of pain in his right knee, which had begun six months before, without any preceding illness or trauma. The pain was severe, constant, and prevented sleep.

Physical examination revealed a fusiform enlargement of the right femoral shaft and localized tenderness on the medial side, just above the mid-shaft. Laboratory examinations gave no unusual findings.

A roentgenogram showed a large fusiform mass of sclerotic new bone on the medial side of the femoral shaft, extending from the lesser trochanter along the cortex to the distal third of the femur (Fig. 3-A). Beneath the mid-point of this mass was a small area of lesser density. This area was found at operation to be a definite cavity, filled with brownish granulations. The cavity was thoroughly cleaned out, but no attempt was made to remove all the surrounding hypertrophic bone. Cultures made in the operating room produced no growth, and the wound healed by first intention.

After the operation, there was immediate and complete relief of pain. When the patient was last seen, four years later, he was still asymptomatic. A roentgenogram showed that the remaining hypertrophic new bone was unchanged.

Sections of the material curetted from the cavity showed the center of the nidus (Fig. 3-B). The fibrous-tissue background had unusually large blood spaces and relatively few giant cells. Ossification was fairly well advanced, with numerous heavy trabeculae present in an irregular pattern. Little osteoid tissue was seen in this portion; but in the zone immediately surrounding it, osteoid tissue was present in amorphous masses.

FIG. 3-A

Case 2. Roentgenogram of femur shows dense mass of hypertrophic bone on medial aspect of shaft. Beneath the center of the mass is a small radiolucent area.

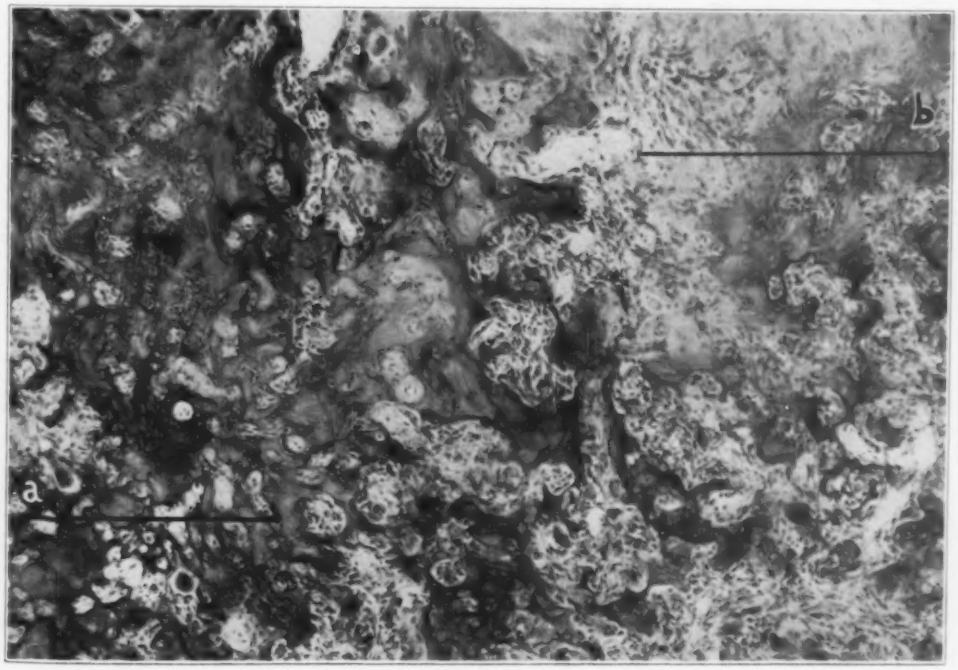

FIG. 3-B

Photomicrograph (× 96) shows vascular fibrous stroma with giant cells. The center of this lesion is almost all irregular bone (*a*). Surrounding it is a zone of amorphous deposits of osteoid tissue (*b*).

FIG. 4-A

Case 3. Roentgenograms show a radiolucent lesion in the distal portion of the radius, surrounded by marked sclerosis. There is the shadow of periosteal new bone on both radius and ulna. (Illustrations have been reversed.)

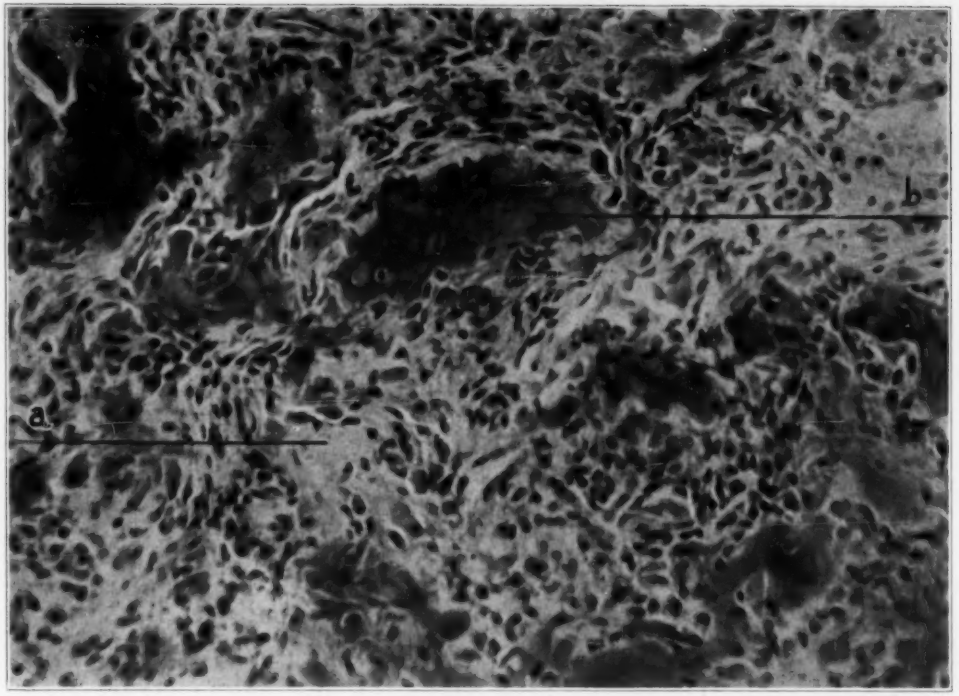

FIG. 4-B

Photomicrograph (× 300) shows immature lesion with little organization. In the fibrous stroma are small irregular trabeculae of osteoid tissue (*a*), and a few where calcification has just begun (*b*).

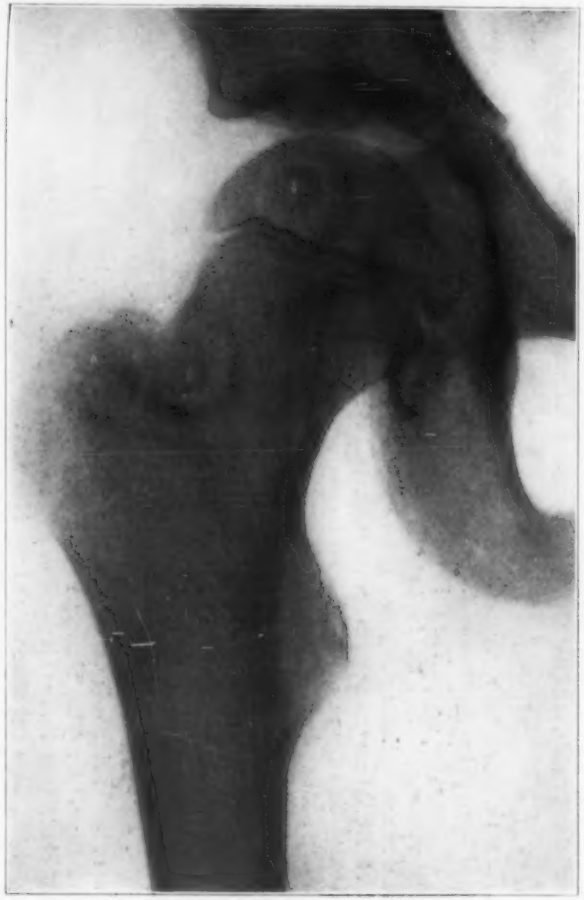

FIG. 5-A

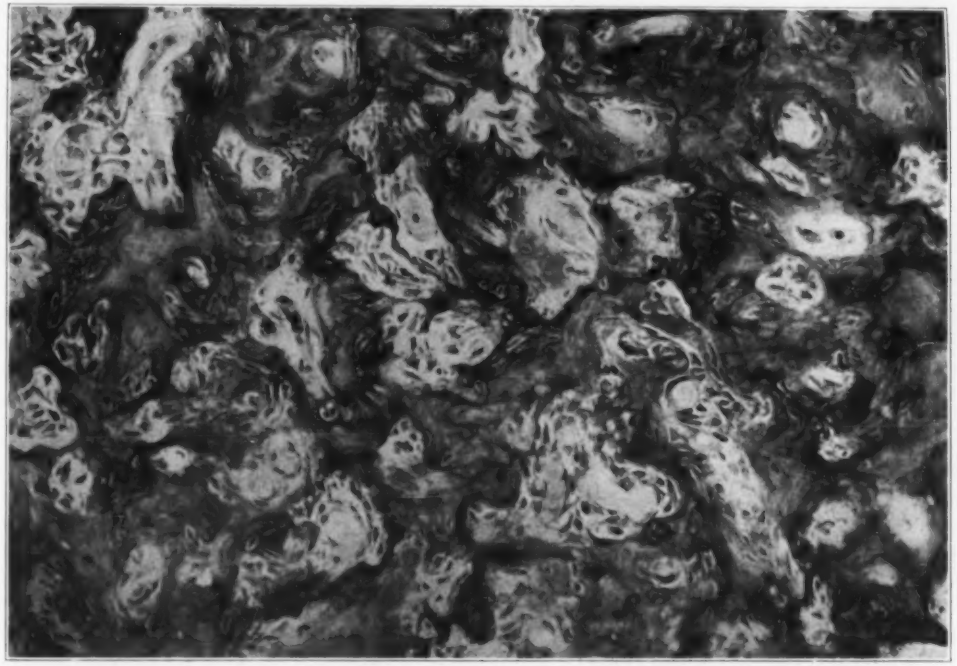

FIG. 5-B

Fig. 5-A: Case 4. Roentgenogram shows a round lesion with a dense center in the greater trochanter. There is a sclerotic ring about the periphery, but minimum reaction of the surrounding bone. (Illustration has been reversed.)

Fig. 5-B: Photomicrograph (× 200) shows nidus of more mature lesion. In the fibrous tissue, there is relatively little osteoid. There are numerous well-formed but atypical trabeculae of bone, which is irregularly calcified.

FIG. 6-A

FIG. 6-B

Fig. 6-A: Case 5. Roentgenogram shows radiolucent center in anterior part of proximal portion of the tibia. It is surrounded by dense sclerosis, and there is considerable thickening of the cortex. (Roentgenogram has been reversed.)

Fig. 6-B: In this photomicrograph (× 12) there are three separate well-developed centers. Some hypertrophic regional bone is visible, but most of the peripheral material is dust, produced by the use of a motor drill.

CASE 3. R. H., an eight-year-old boy, presented himself in November 1944, because of pain in the left wrist. This pain was said to have begun two months before, immediately following a six-foot fall in which the patient landed on outstretched hands. The pain was acute and was localized over the lower portion of the radius. It was always worse at night, and kept the boy from sleeping.

Physical examination disclosed no abnormalities except in the left wrist, which was markedly swollen and warm to the touch. There was exquisite point tenderness over the distal portion of the radius, and so much pain on motion that the patient carried his left forearm cradled in his right. Routine laboratory procedures, including a skin tuberculin test, yielded normal results.

Roentgenograms revealed marked sclerosis with subperiosteal new-bone formation on the lateral aspect of the radius, just above the distal epiphysis (Fig. 4-A). In the center of this mass was an oval area of decreased density. There was also the shadow of periosteal new bone on the adjacent ulna.

At operation, the affected region was readily identified by the gross thickening, but the center could not be seen. Therefore, the entire sclerotic area was excised. The wound healed by first intention, and there was immediate relief of symptoms. The swelling decreased slowly, but was still in evidence one year later, when the patient was asymptomatic.

No nidus could be found grossly among the pieces removed at operation, but the characteristic tissue appeared on the sections (Fig. 4-B). The usual background of cellular fibrous tissue was present, and there were a small number of giant cells. In this tissue were fragmentary irregular trabeculae which were composed mostly of osteoid tissue. Here and there were wisps of bone in the centers of the trabeculae.

CASE 4. C. T., an eight-year-old girl, was seen in March 1940, complaining of pain in the medial portion

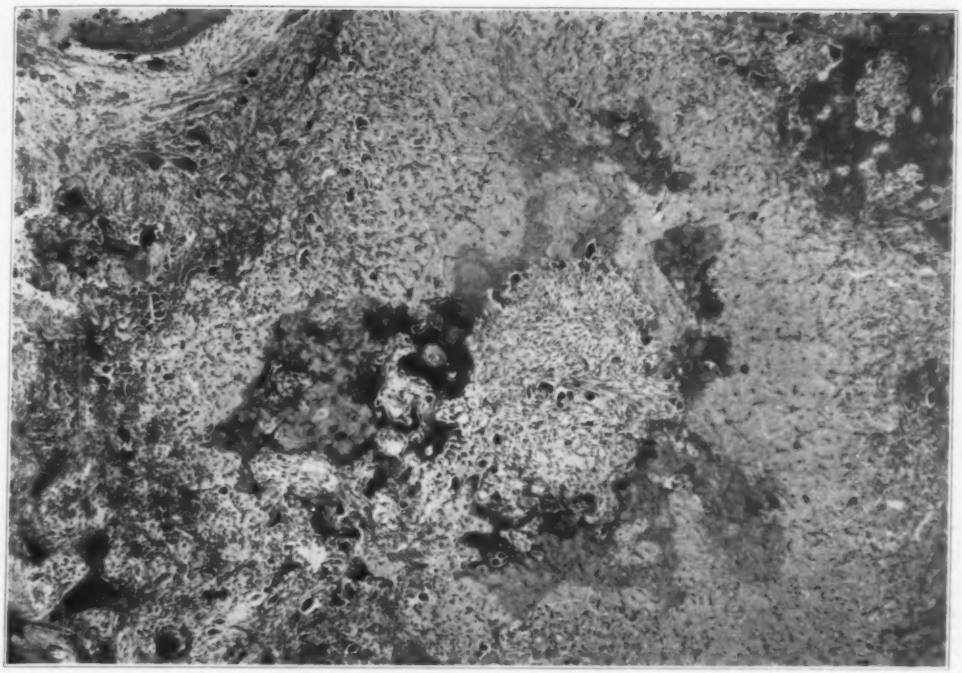

FIG. 6-C

Case 5. Higher-power photomicrograph (× 52) of the middle nidus. The core of vascular fibrous tissue containing giant cells is surrounded by a wide zone of osteoid tissue. Irregular calcification is seen in this ring and also at the periphery.

of the left thigh and knee of eight months' duration. There was no preceding incident of disease or trauma. The pain was never completely absent, had grown steadily worse, and was most severe at night, when it prevented sleeping.

Physical examination disclosed tenderness in the subtrochanteric region of the left femur. Internal rotation of the left hip was limited; atrophy of the thigh muscles was present; and the patient walked with a definite limp. Laboratory tests produced results which were all within normal limits.

The roentgenogram revealed a definite sclerotic lesion in the center of the greater trochanter (Fig. 5-A). It was round and quite well demarcated from the surrounding bone. In the middle was a tiny area of increased density. There was relatively little hypertrophy of the surrounding bone.

Operation showed a small pocket in the ossification center of the greater trochanter, from which grayish fibrous material was easily curetted. The incision healed by first intention, and there was no growth in the cultures made in the operating room. The patient was at once relieved of her complaints, and is still asymptomatic six years later.

Sections of the material taken from the cavity showed the typical structure (Fig. 5-B). The fibrous-tissue stroma was quite dense; it contained many large capillaries and a great many multinucleated giant cells. Osteoid tissue was present, but it was not predominant. Ossification was well advanced, and there were numerous, fairly heavy, irregular trabeculae of immature bone.

This case is remarkable in that the lesion was in an epiphysis.

CASE 5. J. W., a three-year-old boy, had had pain in his left leg for two months before he was seen in August 1946. After one month, a lump had appeared on the upper portion of the tibia, and soon this had become tender. Three weeks before his admission, he began to limp and to waken at night, crying with pain. There was no history of trauma or infection.

Physical examination revealed a firm tender swelling over the upper portion of the left tibia. This area was definitely warm, but not red. The patient walked with a limp, and there was atrophy of the left thigh muscles. Laboratory examinations produced normal results.

The roentgenogram showed a long oval area of decreased density in the anterolateral portion of the upper left tibia (Fig. 6-A). The anterior cortex was expanded, and there was a narrow shell of sclerotic bone surrounding the whole lesion.

At operation, the site of the lesion was clearly marked by roughened periosteal new bone. Total excision was performed with a motor drill. The wound healed without incident, and cultures of the bone produced no growth. The patient was immediately relieved of pain and has remained so.

Sections showed a picture that was characteristic, but slightly unusual (Fig. 6-B). In one end of the block, there were three distinct rounded centers, separated from each other by fibrous tissue and normal bone. Each focus had a central portion, composed of vascular fibrous tissue with many giant cells (Fig. 6-C), and surrounded by a wide ring of masses of osteoid tissue. Here and there within the osteoid tissue were tiny fragments of irregular new bone. At the periphery, regional hypertrophic bone with moderately fibrous marrow was present, and beyond this was completely normal bone.

DISCUSSION

The etiology of these lesions is still unsettled and is the subject of much debate. Most authors who have studied actual examples of osteoid osteoma are in agreement with Jaffe that it is a distinct entity. There exists, however, no such agreement as to whether or not the lesion is a benign neoplasm, as Jaffe contends.

Previous trauma is frequently mentioned as a possible predisposing factor, as it is with almost any skeletal lesion. Among our thirty patients were three with a history of severe trauma to the hand or wrist, who stated that symptoms had begun immediately and had not subsided until operation. Of these patients, two had lesions in the phalanges of the fingers and one in the distal portion of the radius. Five other patients gave a vague history of injury at varying time intervals preceding the onset of trouble. Twenty-one patients stated specifically that there had been no trauma. In view of the known propensity of patients to relate all skeletal disorders to some type of injury, and in view of the small number of such histories related to osteoid osteomata, it seems safe to disregard trauma as of etiological significance.

The only authors who have denied categorically the existence of osteoid osteoma are Brown and Ghormley. They reported a series of twenty-four cases which they considered to be examples of the condition described by Jaffe. Fourteen of their patients were operated upon, and pathological examination of the material removed from ten patients showed "chronic inflammatory tissue". The photomicrographs presented certainly substantiate this diagnosis, and do not resemble the picture of an osteoid osteoma. In two cases, *Staphylococcus aureus* was cultured, and in two, a micrococcus. Quite correctly the authors considered these to be cases of bone abscess. Their reasons for maintaining that osteoid osteomata are all identical solitary chronic bone abscesses are, however, not very clear.

In a paper published in 1942, Brailsford presented several cases with roentgenograms which are compatible with diagnoses of osteoid osteoma. From three of the patients who underwent surgery, *Staphylococcus albus* was cultured. Because of this and the roentgenograms, Brailsford called these lesions chronic subperiosteal abscesses. He then made a general statement that the pathological changes were like those described by Jaffe; however, there are not enough data in Brailsford's paper to establish the similarity. Because of the findings in these cases, Brailsford assumed that all osteoid osteomata are a distinctive variation of an infectious process.

Actually, the weight of evidence is clearly against infection as the etiological agent in osteoid osteoma. The patients never have fever, leukocytosis, or other systemic manifestations. When swelling is present, it is only occasionally warm, and there is no redness. The lesions are always solitary and never recur after complete excision; and after operation the wounds invariably heal by first intention. The few positive cultures which have been reported have usually been of *Staphylococcus albus* or some other common contaminant. In our own series, cultures were made in twenty-two instances. Of these, nineteen produced no growth. One each produced *Streptococcus viridans*, *Staphylococcus albus*, and diphtheroids, all of which are considered to be contaminants. In five cases, guinea pigs were inoculated, and none of these showed evidence of disease. In six additional cases, skin tuberculin tests were negative. Twenty-four of the patients had negative Wassermann or Kahn reactions. It is clear that the history, physical findings, and course of these patients are not consistent with an infectious process.

If additional proof were needed, it is certainly amply furnished by the constancy of the distinctive pathological findings. In no case has evidence of either acute or chronic infection been found. The lesions are always sharply demarcated from the surrounding hypertrophied regional bone. The bone immediately surrounding the nidus might possibly be confused with the bone adjacent to an abscess, because the spaces are filled with fibrous marrow which often contains scattered foci of round cells. This picture does not indicate infection, since it is seen in the reactive zone about many different types of lesions. It is also to be noted that the typical tissue of an osteoid osteoma has never been seen in conjunction with a proved abscess, even in those relatively indolent small abscesses which sometimes occur in patients with multiple foci. Osteoid osteomata are always composed of the same few elements: a background of vascular fibrous stroma containing multinucleated giant cells, and osteoid tissue which is irregularly calcified. The lesions differ from one another only in the pattern in which these components are arranged. They are not related to the activity of the hematopoietic tissue, for they occur with no apparent selectivity in fatty and in active marrow, in the cortex, and even just beneath the periosteum. To date no one has found an osteoid osteoma in the scapula, clavicle, or cranium. Case 4 of this report is the only one in which the lesion was located in an epiphyseal ossification center.

Osteoid osteomata, unlike other benign tumors, are never larger than a centimeter or so in diameter. Once they have reached a mature state they do not grow, although the hypertrophied regional bone may increase to form a large mass. Furthermore, it is not only unusual for benign tumors to be painful, but the pain of osteoid osteomata is out of proportion to their small size.

Nevertheless, in consideration of all the facts, we agree with Jaffe that the osteoid osteoma is not of infectious origin, but is probably best interpreted as a benign tumor.

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CHONDROMALACIA PATELLAE

BY JACOB BRONITSKY, M.D., IOWA CITY, IOWA

From the Department of Orthopaedic Surgery, State University of Iowa School of Medicine, Iowa City

REVIEW OF THE LITERATURE

Terminology

The term "chondromalacia patellae" applies to a circumscribed degeneration of the articular surface of the patella, as evidenced by softening, fibrillation with eventual fissuring, and erosion of the cartilage.

Büdinger, in 1906, was the first to describe this condition as "*traumatische Knorpelrisse*" (traumatic fissuring of the cartilage). To König has been given credit for the first use of the term "chondromalacia patellae" in the literature (1924). Although Aleman has claimed that he has been using this terminology since 1918 in his clinical case records, his report on *Chondromalacia posttraumatica patellae* did not appear until 1928. The disease has been further described as "*fissurale Knorpeldegeneration*" [14, 30] (fissuring cartilage degeneration), "*traumatische Chondropathie der Patella*" [8, 17, 21, 33], "chondritis of the patella", "traumatic chondritis" [10], "traumatic fibrillar degeneration" [20, 31], "traumatic degeneration of the articular cartilage" [38], and "traumatic osteochondritis" [11].

The term "chondromalacia patellae" has recently become widely accepted [6, 9, 22, 23, 24, 28, 34, 37] and is being used almost exclusively in the Scandinavian literature to describe this disease. It will also be used in this report.

Etiology

Although chondromalacia of the patella has been recognized for forty years, there is still a lack of complete agreement among observers as to the etiology.

Trauma as the primary factor for the degeneration of the patellar cartilage was suggested by Büdinger in 1906 and was accepted by many of the earlier authors, such as Axhausen (1919), H. Fründ (1926), and Aleman (1928).

However, in many patients, a history of trauma could not be elicited. Aleman explained these cases on the assumption that the patients sustained minor injuries during childhood, which could not be recalled. These minor traumata were sufficient to break the smooth surface of the cartilage, which is known for its inadequate power of repair. The continuous wear and tear of the normally functioning joint further aggravated the damage. Those cases of patellar degeneration with no or negligible clinical symptoms referable to the knee, Aleman termed "*latente Chondromalazie*"; those with clinical manifestations he called "*manifeste Chondromalazie*". But Karlson, in 1939, when he reviewed sixty-two cases, which included twenty cases operated upon earlier by Aleman, concluded that his findings could not prove Aleman's contention that chondromalacia of the patella was always due to trauma. In an investigation of 604 patients, Hinricsson, using Aleman's clinical criteria for diagnosing the disease, also found a discrepancy between the frequency of trauma and the presence of chondromalacia of the patella; only two-thirds of his cases showed agreement.

Other authors have agreed with Kulowski that, although trauma is the primary exciting cause, a predisposed constitution and the peculiar mechanism of the knee joint also play important roles in the formation of the degenerative changes found in chondromalacia of the patella.

The similarity between chondromalacia patellae and degenerative arthritis has been recognized by many observers. Läwen (1925) and König (1928) suggested the early

resection of the degenerated cartilage as a means of preventing the development of degenerative arthritis. This suggestion has not been widely accepted. Erb, in 1933, reported a ten-year follow-up of eighteen patients operated upon. He found that, although subjective improvement was noted in all patients, the operation did not retard the further development of degenerative arthritis. These results have been verified by other observers [24].

The present theory is that degeneration of the patellar cartilage can exist with or without trauma. A large number of pathological investigations have shown that degenerative changes are frequently found in the knee; these changes increase with age. Heine, in 1926, reported his observations in the examination of 1,002 cadavera of patients who died between the ages of fifteen and ninety-five. He found that the greatest number of degenerative changes occurred in the knee joint. These changes occurred first in the patella and subsequently reached their greatest development in this bone. In 49 per cent. of these cases, the same degree of change was evident in both knees; in 35 per cent., the condition was worse in the right knee; and in 16 per cent., the left knee showed the greater damage. No sex difference was noted.

Of forty-four cadavera, Läwen found changes in the knees of twenty-six. These changes were most pronounced on the cartilage surface of the patella, and in most of the cases both patellae were involved. Silfverskiöld found that, in 170 autopsies, 24 per cent. of the individuals between fifteen and twenty years of age had a mild degree of degeneration of the patella.

Øwre investigated 124 cadavera with presumably healthy knee joints. Although there had been no complaints referable to the knee, he found degeneration of the patella as follows:

1 to 19 years of age, 5 cases out of 18 (all over 14 years old)
20 to 29 years of age, 27 cases out of 32
30 to 39 years of age, 24 cases out of 26
40 to 59 years of age, 30 cases out of 32
60 to 80 years of age, all 16 cases

The degree of severity of involvement increased with age.

In 1942, Bennett, Waine, and Bauer reported their study. The purpose of their investigations was to familiarize themselves with the so-called normal knee joint at each decade of life. They found that all joints obtained from individuals beyond the second decade of life exhibited alterations similar to those observed in degenerative arthritis; and the degree of degeneration in the individual specimen was not proportional to the degree of arteriosclerosis found in the peripheral vessels. They concluded that articular cartilage remains normal for only a short time following complete maturation.

Heine, Keefer and his associates, and Silfverskiöld found no relationship between the extent of degeneration and the occupation of the individual.

In the clinical investigation of 640 patients, Hinricsson found that the frequency of occurrence in different age groups was about the same as that reported by various other investigators.

Freund, in 1939, emphasized the belief that, under normal conditions, joint cartilage requires friction and pressure to remain healthy; any variation of these stimuli, either above or below the physiological optimum, if active over a long period, would be deleterious to the joint cartilage. This had been previously shown by Müller and Benninghoff (1924) in animal experiments.

In 1944, Hirsch, after an intensive study of patellae removed at autopsy and at operation, reported his observations on the physical, histological, and chemical investigations in chondromalacia of the patella. He found that normal cartilage could adapt itself functionally to an increased pressure with almost complete recovery of its elasticity, provided the pressure per unit area did not exceed the tensile strength of the cartilage and was maintained for a short duration. However, if the pressure did not exceed the tensile

strength, but was repeated often or was maintained over too long a period, an impairment of elasticity resulted. Since he believed that the normal elasticity of the cartilage, and its resulting pumping action, was essential to its nourishment, he concluded that "nutritional disorders, due to unfavorable loading, may be one of the main reasons for pathologic changes in the cartilage of the patella". Furthermore, from his studies on the chondroitin-sulphuric acid content of cartilage, he concluded that fissures develop in an already altered cartilage.

Lanier, in 1946, concluded from his experiments with mice that mechanical factors were subordinate in the production of degenerative joint disease. He agreed with the suggestion made by Bennett, Waine, and Bauer that the metabolic processes of aging cartilage will have to be comprehended before the problem of degenerative joint diseases can be solved. Sundt, in 1938, stated that chondromalacia of the patella is a constitutional disease, and suggested that the primary cause was an injury to the synovial membrane, which then produced an abnormal fluid. He assumed that, since the articular cartilage to a large extent received its nourishment from the synovial fluid, an abnormal composition of the latter would cause nutritional disturbances in the cartilage and lead to its degeneration.

FIG. 1

Thomas M., aged twenty-one. Chondromalacia of the patella.

In 1945, Cox expressed the opinion that the true pathological change was in the underlying cancellous bone, and that the change in the articular cartilage was entirely secondary.

To summarize the present trend of thought:

1. Our knowledge of the physiology and nourishment of cartilage is still incomplete.
2. Degeneration of cartilage without trauma does exist.
3. Acute trauma or static deformities can influence the origin and progress of the disease.
4. The question of constitutional disposition and heredity as etiological factors is still unsettled.

Incidence of Chondromalacia of the Patella

In 1927, Aleman reported that, in 220 arthrotomies performed on soldiers in the third decade of life, he found in one-third of the cases a focus of softening and fissuring of the articular surface of the patella.

Darrach, in 1935, reviewed 157 operations for internal derangement of the knee and found a diseased patella in thirty-six patients. In 1939, the same author noted, in 376 arthrotomies, that in 6.8 per cent. of those patients with a degenerative lesion of the patella, it was the only demonstrable pathological change found in the knee.

Hilzensauer, in 1936, reviewed 1,000 arthrotomies performed at the hospital in Graz, Austria. He found chondromalacia of the patella in forty-eight cases. Chaklin, in 1939, found thirty-eight cases in 159 operations on the knee.

In recent years, a number of cases of chondromalacia of the patella have been reported at various military hospitals. At a Naval hospital, Anderson, in 1944, found ten cases in fifty successive arthrotomies. At an Army hospital, Soto-Hall, in 1945, found twelve cases

in sixty-five arthrotomies performed for chronic knee complaints. In the same year, Cave, Rowe, and Yee reported that, in 124 arthrotomies performed at an Army hospital, they saw nine cases in which the only cause for the symptoms was the degenerative lesion of the patellar cartilage.

The youngest patient in whom chondromalacia of the patella has been diagnosed clinically was a ten-year-old girl,—a case reported by Hinricsson. However, the youngest patients in whom the diagnosis was verified at operation have been thirteen years of age. In the present study, the youngest patient was a thirteen-year-old girl with cerebrospastic quadriplegia, whose patella was excised because of degenerative lesions of the articular surface (Fig. 4).

Site of the Patellar Lesions

The earliest detectable lesions are most frequently located on the medial facet, less frequently in the center, and occasionally on the lateral facet of the patella. In severe cases, the entire articular surface may be involved.

This predilection of the disease for these different sites has been explained by Wiberg on the basis of the peculiar anatomy of the patellofemoral joint. He made cross sections and roentgenographic studies of knees at different angles of flexion. He was able to show that, when the knee is flexed 20 to 50 degrees, the whole of the lateral facet and only a small part of the medial facet of the patella are in contact with the articular surface of the femoral condyles, whereas the greatest stress is on the central longitudinal ridge. As the flexion of the knee is increased, the pressure on the ridge diminishes, until at 90 degrees it

FIG. 2-A

Bessie M., aged forty-four. Advanced chondromalacia of the patella, with fibrillation and fragmentation of the superficial layer of the cartilage, and with undermining of the ulcerated area.

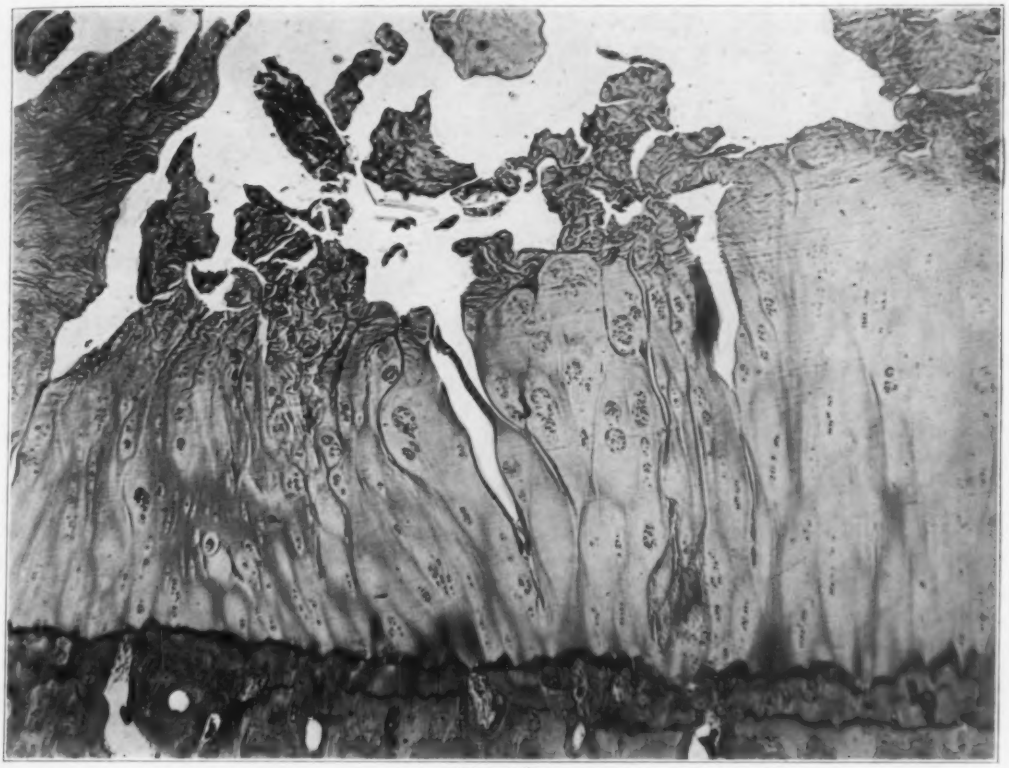

FIG. 2-B

Center of ulceration seen in Fig. 2-A, showing the fissures reaching into the deeper layer of the cartilage. Weichselbaum lacunae are evident. The subchondral bone is sclerotic, with a double line of calcification. Small tongues of fibrous tissue have penetrated the subchondral layer.

disappears completely, for at this angle the patella reaches the intercondylar notch of the femur. At this point, contact is maintained only by the larger lateral and the smaller medial facets. During flexion, the lateral patellar facet continues in good congruence with the lateral femoral condyle, while the medial facet of the patella, from an angle of 90 degrees and upward, opposes a convex surface to the convex femoral condyle.

Pathology of Chondromalacia Patellae

The degenerative changes found in cartilage have been studied and described by many investigators. To summarize:

Gross Examination: In the early stage, the cartilage loses its bluish-white, shiny, translucent appearance and becomes opaque, yellowish, and softer than normal. As the degeneration proceeds, cracks and fissures appear, which give a frayed appearance to the surface. With the continued progress of the disease, the cartilage is gradually ground down, until the underlying bone is exposed. The exposed bone soon becomes sclerotic and eburnated. In extreme cases, the entire articular surface will be denuded of cartilage. Marginal osteophytes have been shown to appear relatively early and, according to Øwre, will be best developed in those areas where the degenerative lesion has reached the cartilaginous edge. Frequently, the synovial membrane is secondarily involved and shows evidence of non-infectious inflammation.

Microscopic Examination: The early lesions are featured by fibrillation of the superficial layer of the cartilage; the deeper adjacent layer is swollen, as revealed by its abnormal staining, and contains relatively few cells. The individual cells degenerate, increase in size, and are heaped together in small groups. As the clefts and fissures form, the large cell clusters or lacunae of Weichselbaum appear in the vicinity. The thickness of the cartilage

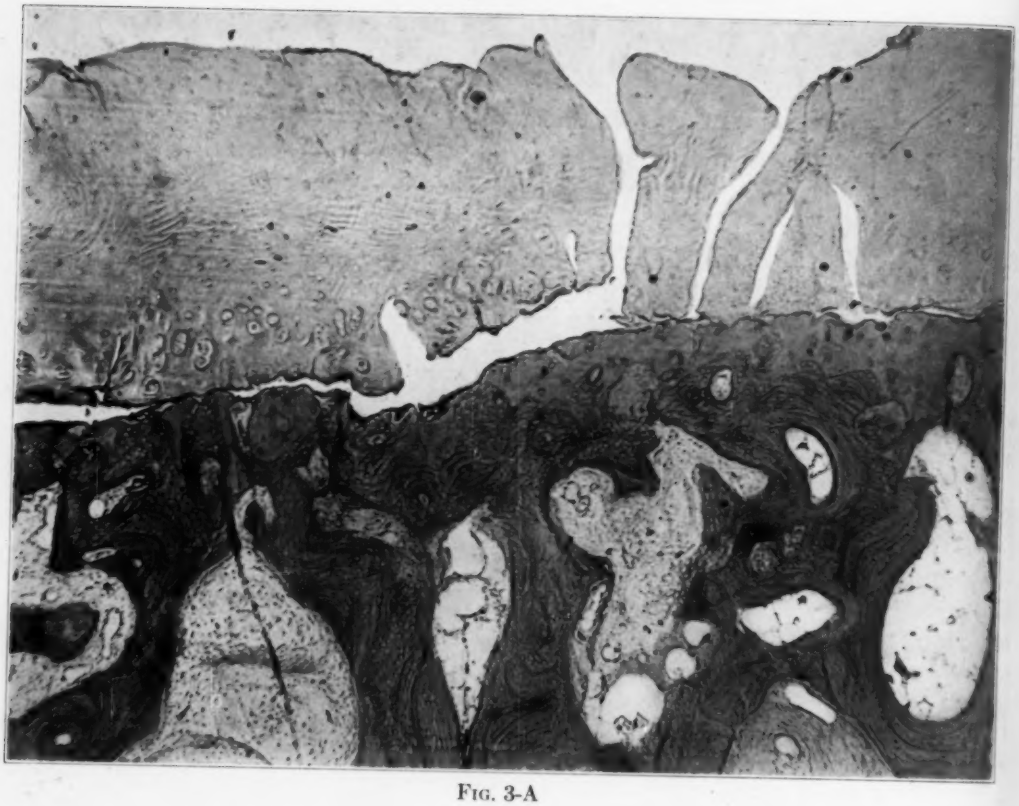

FIG. 3-A

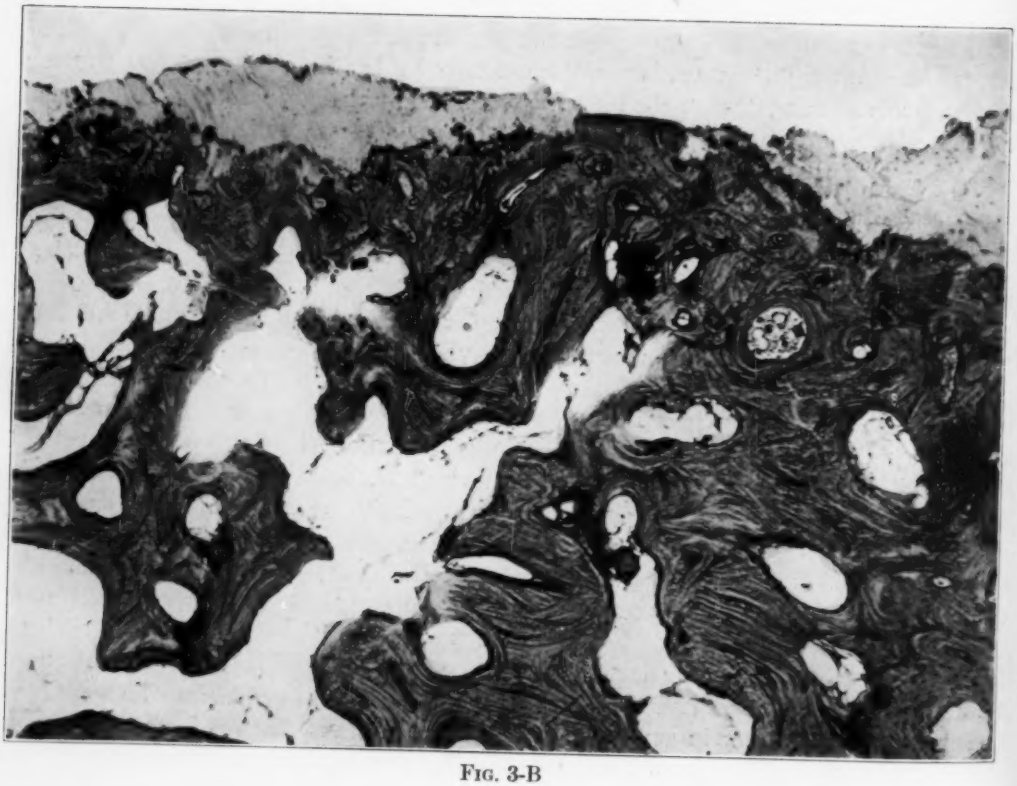

FIG. 3-B

FIG. 3-D

FIG. 3-C

Fig. 3-A: Ellen S., aged twenty-one. Severe chondromalacia of the right patella. The cartilage is fissured and is separated from the underlying bone. There are islands of newly formed cartilage over the denuded bone. Islands of fibrocartilage and hyaline cartilage are deeply seated in the marrow spaces.

Fig. 3-B: Area from the center of the ulcerated area seen in Fig. 3-A. The cartilage is almost completely gone. The subchondral bone shows advanced bone sclerosis and eburnation of the surface.

Fig. 3-C: An advanced case of chondromalacia of the left patella, with an isolated mass of cartilage in the bone marrow indicated by arrow.

Fig. 3-D: A higher magnification of the area in Fig. 3-C indicated by arrow. The cartilage may be seen to be forming new bone.

is progressively reduced. The subchondral bone shows no conspicuous changes until the overlying articular cartilage has become markedly altered. When the erosion extends for a considerable distance into the hyaline matrix, the marrow of the subchondral bone responds with various degrees of fibrous proliferation; fibrous tongues often extend through the zone of calcification. In close proximity to this newly formed fibrous tissue, there may be found cartilage and bone. Occasionally, an isolated mass of cartilage will be found in the marrow spaces of the subchondral bone.

Clinical Symptomatology

The patient with chondromalacia of the patella usually has a history of chronic knee discomfort of varying degrees of severity. The usual complaint is of pain, frequently accompanied by weakness and a tendency of the knee to buckle. This is noted especially when climbing a hill or walking up and down stairs. Often there will be difficulty in fully extending the knee. Repeated momentary locking of the knee may be present. This is not a true locking. The patient experiences severe pain of a few seconds' duration, which may pass away entirely or may be followed by an effusion into the joint. Actual locking may occur, and it is caused by free bodies which have broken loose from the surface of the patella. Frequently, the knee aches, especially after sitting for some time in one position or with the legs crossed. Occasionally the patient will complain that the knee is stiff on arising in the morning and limbers up only after walking.

Crepitation of the patella has been emphasized as the most characteristic sign of this disease. Aleman stated that the location of the crepitation under the patella is pathognomonic. Karlson believed that an experienced examiner can make a diagnosis of chondromalacia of the patella on the basis of the location, hardness, coarseness, and quantity of the crepitation. The crepitation can be elicited with the patient supine, by extending the knee from a flexed position. Sometimes, in order to bring out the crepitation, it will be necessary to have the patient stand up and bend the knee, while the examiner keeps his fingers on the patella. The crepitation has been described as varying from a single click or a soft velvet-like sensation of roughness, to a creaking, crunching, grating sound, which can be heard at a distance of several feet. However, Øwre has been able to demonstrate that degeneration of the patellar cartilage can exist in the absence of crepitation. According to him, crepitation indicates cartilage degeneration, but the absence of crepitation does not rule it out. Fluid in the knee might separate the contacting surfaces.

Pressure pain over the patella is often present. This is elicited either by pressure on the patella with the knee in flexion of 45 degrees or, in the extended and relaxed knee, by pressing the patella against the medial femoral condyle. This pain has been described as a dull, disagreeable, aching pain, which is comparable to a toothache.

Frequently the synovial membrane is thickened and tender, especially over the medial border of the patella and over the plicae alares.

Other symptoms that may occur are effusion into the joint, swelling of the subpatellar fatty tissue, and atrophy of the quadriceps.

Aspiration of the knee effusion will usually show a clear fluid; seldom will it be cloudy. There is no evidence of infection, and occasionally pieces of cartilage will be found in the fluid.

Roentgenograms are of almost no help in making the diagnosis in the early stages. The evidence of osteophyte formation will verify the presence of degeneration of the articular cartilage; but, in a large number of cases, even the osteophytes do not show up on the roentgenograms. Haglund described an indentation of the patellar cartilage which he attributed to contusion of the articular surface. Läwen and others have been able to show that this indentation is a frequent finding and has no relationship to trauma or to chondromalacia of the patella.

PRESENT STUDY

Although Aleman and Karlson have insisted that the clinical symptomatology described is pathognomonic for chondromalacia of the patella, there are many other observers who find that these symptoms are applicable to several knee conditions. Timbrell Fisher, for example, states that slight adhesions involving the alar fat pads may give rise to a surprising amount of disability in the form of pain, synovial effusion, weakness, tenderness, muscle wasting, and a sensation of "giving way" of the joints, but not as a rule to actual locking. These symptoms are very similar to those described for chondromalacia patellae. He further states that crepitus is caused by the movement of hypertrophied synovial fringes.

The purposes of this paper are:

1. To analyze the relationship between the symptoms and the pathological findings.
2. To evaluate the results of operative intervention in chondromalacia of the patella.

This study is based on case records, borrowed both from the private files of Dr. Arthur Steindler and from the clinical files of the Department of Orthopaedic Surgery, University of Iowa. Only those cases in which the degeneration of the patellar cartilage was verified at operation were included in this study. The case histories of twenty-nine patients were reviewed (these included three cases reported by Kulowski in 1933). There were sixteen female and thirteen male patients. Two female patients had pathological conditions in both patellae. A total of thirty-one knees were involved.

At operation, there was frequently found, besides the patellar degeneration, a coexisting synovitis, a hypertrophied fat pad, free bodies, a torn meniscus, or a combination of several of these conditions.

In an attempt to evaluate the symptoms, the cases were arranged in the following six groups, depending upon the type of pathological involvement found:

Group I includes all cases in which the pathological condition was localized to the patellar cartilage alone. Theoretically, all clinical symptoms produced in this group should be due to the degeneration of the patellar cartilage. There were six patients with an average age of 21.6 years and an average duration of symptoms of 2.7 years.

Group II includes all cases in which an acute or chronic inflammation of the synovial membrane coexisted with the degeneration of the patellar cartilage. This group can be considered as representing a further stage in the degenerative process; it includes four patients with an average age of 29.6 years and an average duration of symptoms of eighteen months. The fifth patient's symptoms had been present for eight years.

Group III includes all cases in which, besides a chondromalacia of the patella, there were found cartilaginous bodies, either enclosed in the synovial membrane or lying free in the joint. As synovial changes were usually present also, these cases might be included in Group II. However, since these bodies could possibly produce symptoms independent of the other pathological changes, these cases were grouped separately. There were five patients in this group with an average age of 22.6 years and with an average duration of symptoms of 2.6 years. The sixth patient, Ellen S., aged twenty-one, had complaints referable to the right knee that had existed as long as she could remember (Figs. 3-A and 3-B).

Group IV includes all cases in which the pathological changes were extensive enough to warrant the diagnosis of osteo-arthritis or degenerative arthritis. There were five patients in this group with an average age of forty-seven years and a duration of symptoms of 2.3 years. The sixth case involved the left knee of Ellen S., mentioned in the previous paragraph (Figs. 3-C and 3-D).

Group V includes all cases in which there was a torn meniscus, regardless of the other degenerative changes in the knee. Cases with the diagnosis of hypermobile meniscus were not included in this group. There were six patients with an average age of 29.7 years and an average duration of symptoms of five years.

Group VI includes two cases: one of a generalized atrophic arthritis; the other of mono-articular synovitis of the knee, following the incision and drainage of a Brodie's abscess in the distal end of the tibia of the same side.

It is obvious that the above division is an artificial one, as there is no sharp demarcation between the different phases of the disease.

At the time of operation, the ages of the female patients ranged from thirteen to fifty-five years; those of the male patients ranged from nineteen to fifty years. One patient was thirteen, another sixteen, and two patients were nineteen years of age. Fourteen (48.3 per cent.) were in the third, and five were in the fourth decades of life. The remaining six patients were over forty years of age. The average age of the twenty-nine patients was thirty years.

A history of acute trauma was denied in eight (25.8 per cent.) of the thirty-one knees involved. The types of trauma reported in the remaining twenty-three cases were as follows:

Direct blow to the knee	12 cases
(Includes one case of multiple sclerosis with a history of repeated falls)	
Twisting injury to knee	4 cases
Tackled or clipped, while playing football	3 cases
Injured while pole-vaulting	1 case
Traumatic dislocation of the patella	2 cases
Recurrent dislocation of the patella	1 case

In the twelve cases of direct trauma to the patella, the force of the blow varied from a kick in the knee by a cow to any force sufficient to fracture the patella. The average history was that of striking the knee against a hard surface. A comparison of Group I with the other groups, especially Group V, shows that a history of trauma is of little value in differentiating between pure chondromalacia of the patella alone and other coexisting lesions. The typical history for the occurrence of a torn meniscus is often that the patient was tackled or clipped while playing football. In the three cases of this study, only one patient had a torn meniscus. The other two showed no involvement of the menisci.

The following three cases emphasize how difficult it is at times to evaluate the relationship of trauma to degeneration of the patellar cartilage.

CASE 1. Gerald H., aged twenty, injured the left knee while pole-vaulting in 1925. In 1927, he jumped five feet and again injured the knee. After these accidents, he had had recurrent locking and pain over the lateral aspect of the knee.

On January 13, 1933, arthrotomy was performed for the removal of the lateral meniscus. No other pathological changes were noted in the joint, although it was eight years after the first trauma and six years after the second.

On August 9, 1933, only seven months later, another arthrotomy was performed; a typical chondromalacia of the patella, with involvement of the synovial membrane, was then evident.

On May 7, 1934, the patient returned, stating that, since February 28, 1934, he had had pain in the opposite knee with swelling and locking and a tendency to "give" on weight-bearing. There was no history of acute trauma; and an arthrotomy, on May 14, 1934, revealed that the medial meniscus was loose, and there was a slight erosion of the medial condyle of the femur. The patella was normal.

CASE 2. Cleo G., aged twenty, stumbled and twisted her left knee on February 12, 1931. This resulted in pain and swelling. A leg brace brought no relief from the pain.

On February 5, 1932, an arthrotomy showed that the knee was normal, except for a redundant strip of fatty tissue, interposed between the articular surfaces of the femur and the tibia. Although this was one year after the trauma, there was no evidence of chondromalacia of the patella.

One year later, on January 26, 1933, arthrotomy revealed a severe degeneration of the patellar cartilage.

CASE 3. Wilma S., aged sixteen, struck her chin against her left knee, while gliding down a fire-escape tube on October 20, 1939. She had moderate pain in the knee. She injured the knee again, while skating, on October 30, 1939.

On July 31, 1940, an arthrotomy, performed after a diagnosis of internal derangement of the knee, revealed a hypertrophic fat pad. Synovial membrane and patella were normal. At this time, nine months after the trauma, there was no evidence of degeneration of the patella, but on January 21, 1942, eighteen months later, arthrotomy revealed chondromalacia of the patella.

On the other hand, two patients with traumatic dislocation of the patella showed marked chondromalacia of the patella, five months and one year, respectively, after the trauma.

Observation of such cases raises the question of the relationship between the duration of complaints and the degree of degeneration found at operation.

Although the number of cases is insufficient for definite conclusions, it was noted that, in the younger patients of the group, the longer the duration of symptoms, the greater was the degree of degenerative involvement of the patella. In the older patients with clinical evidence of osteo-arthritis, such correlation was not evident.

It is not known definitely why, during the process of cartilage degeneration, some patients suffer from continuous discomfort, whereas in others the degenerative process proceeds without any, or with relatively minor, symptoms. In the latter group of patients, the duration of symptoms naturally would not be reflected in the pathological findings.

In the traumatic group, there was, apparently, no relation between the duration of symptoms and the degree of degenerative changes. The amount of degeneration found depended on two factors, both of which are frequently difficult to evaluate. The pathological findings depend, first, upon the amount of degeneration present at the time of the accident and, second, upon the severity of the trauma. Traumatic dislocation of the patella seems to be most detrimental to the cartilage.

Phyllis C., aged twenty, had had injuries to both knees. In 1935, she had twisted her right knee while playing basketball. This resulted in serious discomfort, which was almost continuous. She twisted and injured the left knee in 1939.

On April 8, 1940, five years after the first injury, an arthrotomy was performed on the right knee, and on May 29, 1940, eight months after the second injury, an arthrotomy of the left knee was done. Although the interval since the trauma varied in the knees, the pathological findings revealed almost the same marked fibrillation of both patellae. A free body was found in the intercondyloid notch of the right femur. On the lateral condyle of the same femur was a small defect, which had been filled with fibrous tissue.

FIG. 4

Iris B., aged thirteen, a cerebrospastic quadriplegic. Showing the marked indentation of the right patella, probably due to the continuous pressure of the patella against the femoral condyle.

History of recurrent effusions was not investigated in nine patients; of the remaining twenty-two patients, sixteen reported the presence of recurring effusions, whereas this was denied by six patients; one with recurrent swelling showed normal synovial membrane.

History of weakness or locking in this series includes both true locking and the so-called "staying" or "catching" of the knee.

Twenty-five patients reported this symptom. In nineteen (76.0 per cent.) of these cases, the symptom was present; it was absent in six. It is interesting to note that in Group V, this symptom was absent in two of the six patients.

Gilas Mc. of Group I had true locking three weeks and two weeks prior to admission. The first time locking occurred, it was relieved by manipulation. The second time, it was necessary to apply traction for twenty-four hours before it could be relieved.

Patellar tenderness could not be evaluated, since twenty-three of the twenty-nine case records had no data on the subject.

Points of tenderness were reported in twenty-two case records. They were present in nineteen cases (86.4 per cent.) and absent in three cases. Two of these three patients in whom there was no point of tenderness were found in Group V.

If the six patients of Group V are excluded from the study of this symptom, fifteen of sixteen cases remain in which there was a point of tenderness. Fourteen of these cases had a point of tenderness somewhere along the medial aspect of the knee joint, located as follows:

Over the anterior insertion of medial meniscus	5
Medial to the patella	5
Along the tibial collateral ligament	2
All around the patella	1
To each side of the patellar ligament	1

In one case, the point of tenderness was in the infrapatellar area.

Crepitation or grating of the patella was present in twenty-three of the twenty-five case histories (92 per cent.) which reported this sign, but insufficient data precluded any attempt to evaluate the quality of the sound. Of special interest is Group I, in which the presence of this sign was noted in five of the six patients.

Selda R., in Group II, had no crepitation, although the synovial membrane was described as "grape-like".

When Wilma S. (Group I) was examined previous to arthrotomy, no grating was heard. The patella was found to be normal. Examination previous to the second arthrotomy revealed soft grating. The patella then showed a marked chondromalacia.

Swelling of the knee was looked for at the time of preoperative examination in twenty-four cases. Nine patients (37.5 per cent.) showed this swelling. In fifteen cases (62.5 per cent.), effusion of the knee was not demonstrable clinically. The nine cases with positive swelling were distributed in the groups as follows:

Group I	None of 4 cases
Group II	2 of 4 cases
Group III	1 of 5 cases
Group IV	3 of 5 cases
Group V	1 of 4 cases
Group VI	2 of 2 cases

In one case of osteochondromatosis, the firm nodules were palpable.

With the exception of the cases of osteo-arthritis, in which the presence of osteophytes could be demonstrated, all roentgenograms in this study were reported as negative for bone or joint pathological changes.

One exception, Iris B., a thirteen-year-old girl with cerebrospastic quadriplegia, showed a marked indentation in the articular surface of the patella; this was probably due to the continuous pressure of the patella against the femoral condyle (Fig. 4).

RESULTS OF OPERATION

All patients were operated upon only after conservative therapy had failed to give relief.

Several operative procedures have been recommended in the literature for the treatment of chondromalacia of the patella. All reports of these procedures have been favorable. In this series, four different surgical procedures were used:

1. Chondrectomy, in which the degenerated cartilage was shaved off with a sharp blade until normal-appearing cartilage was reached.

2. The same procedure was used, but the patellar surface was then covered with synovial membrane.

3. Patellaplasty, in which the entire patellar cartilage and subchondral bone were removed with a saw. This left a bony shell, the raw surface of which was then covered

with synovial membrane. Where the synovial membrane was degenerated, fascia or quadriceps tendon was used to cover the raw patellar surface.

4. Complete excision of the patella.

In all the cases, any other coexisting pathological condition noted at operation was removed or corrected. Synovectomy for removal of a mildly hypertrophic or congested synovial membrane was not performed.

Eighteen patients were followed from one to seven years after treatment, with an average follow-up of two years and three months; in six of them, the follow-up period was from five to nine months; in four, it was less than five months. In three cases, there was no follow-up, because these patients were sent back to the physicians who had referred them as soon as they were able to leave the Hospital.

The results were tabulated as good or poor, depending upon the patient's subjective response to surgery. The result was considered good when the patient obtained both subjective relief from his complaints and good function of the limb. The result was noted as poor when the patient failed to obtain either satisfactory alleviation of his complaints or good function of the limb. In some, further surgical intervention finally produced relief from symptoms. Subjective improvement was usually noted a short time after operation.

In one patient who was followed for four weeks after treatment, a free body was removed from the knee. In three patients with a follow-up of six weeks, seven weeks, and ten weeks, respectively, a chondrectomy was performed. The results in these last four patients were good, but are not included in this analysis.

Chondrectomy was performed in eight of the cases included in this study with six good and two poor results. Of the two poor results, one occurred in a patient with a coexisting subluxation of the patella. A "reefing" of the capsule was also done at the time of operation. The second patient had a congenital slipping of the patella. At the time the chondrectomy was performed, a hypermobile medial meniscus and a hypertrophic fat pad were removed, and a Goldthwait tendoplasty was performed on the patellar tendon.

In the three cases in which synovial membrane was used to cover the patellar surface after chondrectomy, there were two poor results and one good result. The two poor results occurred in the same patient, Phyllis C. Both patellae were later excised, with a good result in one knee and a poor result in the other.

All four cases in which patellaplasty was performed gave poor results. One patient had multiple sclerosis, a second patient had generalized atrophic arthritis, and in a third case, the synovial membrane was degenerated and plastered down, with a pannus over the femoral condyles and the patellar surface. A strip of the quadriceps tendon was used to cover the raw patellar surface. In the fourth case, Ellen S., both patellae were involved. In the right knee, in which the patellaplasty was done, the result was poor. Arthrotomy was again performed, and the synovial membrane, previously used to cover the patellar surface, was removed. This procedure gave a good result. However, in the left knee, only a hypertrophic fat pad and a free body were removed; the patella was left untouched, and the result was good.

In the six cases in which the patella was excised, there were five good results and one poor result. The poor result occurred in the patient with chronic mono-articular synovitis, following an operation for a Brodie's abscess in the distal end of the tibia of the same extremity. The functional result of the knee was good, but the swelling persisted. In all the cases of patellectomy, the function of the knee was good, except in the one knee of Phyllis C., mentioned previously.

There were two osteo-arthritic cases: Marguerite B., aged thirty-four, in whom a congenital subluxation of the patella was treated with a medial transplantation of the patellar tendon; and Maxine H., aged fifty-five, in whom an arthrotomy was done on the diagnosis of osteochondritis dissecans, and the free body was not found. In both of these cases, the patellae were left intact and the results were good.

CONCLUSIONS

Chondromalacia of the patella can be a disabling disease in a young, otherwise healthy individual. A summary of the clinical symptoms shows that in a patient in his early twenties, with a history of chronic knee discomfort which does not respond to conservative treatment, and which includes weakness, tendency to locking, occasional swelling of the knee, and pain especially on the medial side of the joint, the diagnosis of chondromalacia of the patella must be strongly considered. If patellar crepitation or grating is present, this diagnosis can be made with a greater degree of certainty. In young individuals, a positive diagnosis of chondromalacia of the patella can only be made at time of operation. In older individuals, a positive diagnosis can be made, based entirely on the described clinical signs and symptoms.

All of the cases in Group I were characterized by the absence of swelling at preoperative examination. At best, this symptom is of dubious diagnostic value. A certain amount of fluid can be present without a noticeable change in form of the joint. In 50 per cent. of the remaining groups, this sign was also absent. The presence of osteophytes will help in the diagnosis of osteo-arthritis; otherwise, none of the symptoms distinguish Group I from the other groups or the other groups from each other.

There were no specific signs or any combination of signs that could be attributed to the existence of free bodies or a torn meniscus in the joint. Usually, the relatively increased intensity of the described complaints will indicate the possible presence of these conditions.

In regard to the surgical treatment, it was found that patellaplasty or chondrectomy, combined with some form of covering for the articular surface, gave consistently poor results and could not be considered of any value in the treatment of this disease. This was obvious as far back as 1933, when the last patellaplasty was performed in this Clinic.

The surgery of choice is either the partial chondrectomy or the patellectomy. Chondrectomy gave good results in 75 per cent. of all the cases in which it was performed. The excision of the patella gave good results in all cases except one, where a primary synovitis was present. When synovitis is present with chondromalacia of the patella, synovectomy is not required, since this condition usually clears up after excision of the patella. The age of the patient has little influence on the choice of surgical treatment. Often the decision as to the type of operation to be performed will have to be made after the knee joint has been exposed, and the degree of degeneration has been determined. Chondrectomy should be reserved only for those cases in which the patellar cartilage and surrounding soft tissue are mildly or moderately involved. In all cases in which there is a severe involvement of the synovial tissue, the patellectomy will give best results. Any free bodies and torn menisci that might be present should, naturally, be removed.

The youngest patient in whom a patellectomy was performed was thirteen years of age; the oldest patient was thirty-six. In all cases, the functional results were good. The follow-up period ranged from five months to two and one-half years, with an average of fourteen months.

In conclusion, chondromalacia of the patella is a relatively frequent condition in both young and old. In all patients who do not respond to conservative treatment, surgery will produce definite and lasting relief from subjective symptoms.

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TREATMENT OF UNUNITED FRACTURES BY ONLAY BONE GRAFTS WITHOUT SCREW OR TIE FIXATION AND WITHOUT BREAKING DOWN OF THE FIBROUS UNION *

BY DALLAS B. PHEMISTER, M.D., CHICAGO, ILLINOIS

From the Department of Surgery of the University of Chicago

The most important factors responsible for recent advances in the treatment of ununited fractures have been improvement in the methods of bone-grafting, prevention and control of infection by antibiotics, and the performance of more extensive and finished operations, based on support of the circulation by adequate blood transfusion. The type of operation used varies with many factors,—such as the bone involved, the location of the fracture (whether in the shaft or in the end of the bone), the position of the fragments, and the presence or absence of infection.

The operative technique for ununited fractures of the shafts of the long bones, which have not become infected, has become a standard procedure for the majority of the surgeons of this country. Briefly, it consists of incision at the fracture site, reflection of the soft parts from the exposed side of the bone, breaking down of the fibrous union or pseudarthrosis, separation of the soft parts from the entire circumference of the fragment ends for from 2.5 to 5 centimeters, removal of callus from the fracture surfaces and the medullary canal, correct approximation and alignment of fragments, and then onlay of a broad, long, whole-thickness bone graft, fixation of the graft to the fragments by metal screws, closure of the soft parts, and immobilization of the extremity, by encasement in plaster-of-Paris. The tibia has been the usual source of grafts; but recently iliac grafts have increased in popularity, because of the good results obtained with them in World War II. Metal plates are sometimes used, either in addition to or in place of the grafts.

The rationale of the procedure is as follows: The removal of callus and the freeing of the fragment ends permit reduction and alignment, and stimulate osteogenesis. The graft bridges the fracture and affords internal fixation; and surviving osteoblasts along its periosteal and endosteal surfaces are an additional source of osteogenesis. Bony union and a good functional result are usually obtained.

There are, however, certain drawbacks: The amount of trauma is proportionately great; tissue, including the ends of the bone, may be devitalized; the rigidly fixed graft may become fractured; and infection is more frequent than in clean operations of the same magnitude, performed on soft tissues. These factors are responsible for a certain proportion of non-unions and osteomyelitis. If the fracture is of a large bone and complex, the operative repair may be long, difficult, and bloody; and shock may supervene, with serious consequences, unless this condition is properly managed. Although the objections to this type of procedure have greatly diminished since penicillin and adequate blood transfusions have been used, they are still of sufficient magnitude to justify a further search for simpler operations.

Two common erroneous teachings have retarded the development and acceptance of a much more simplified technique [3, 7], applicable to ununited fractures of the shaft, in which the position of the fragments is quite acceptable were union present. The first misconception is that, in all cases of non-union, the fracture line should be broken down, and the intermediary and medullary callus should be removed from the fragment ends. The second is that the graft should always be firmly anchored to the fragments by screws or encircling ties.

An experience, twenty-four years ago, with an ununited fracture of the mandible

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FIG. 1-A FIG. 1-B

Fig. 1-A: Case 1. Non-union of mandible of five months' duration.
Fig. 1-B: Four months after simple onlay bone graft.

showed that it was possible to obtain bony union and a good functional result without adherence to these teachings. The fracture in a twenty-two-year old woman (Case 1) was of five months' standing, and had been infected from communication with the mouth, but the wound had been healed for two and one-half months. A roentgenogram (Fig. 1-A) showed the fragments were well aligned, but with no sign of ossification of the intermediary callus. To have denuded the fragment ends and cleaned out the intermediary callus would have opened a wound in the mouth and invited reinfection, and to have fixed the graft to the fragments across the fracture site by screws or ties would have necessitated a relatively long and disfiguring skin incision. The procedure employed was as follows: A short incision was made on the under surface, and the periosteum was separated from the medial side of the fragment ends sufficiently to permit the onlay of an iliac graft, measuring approximately 4 by 1.5 by 0.5 centimeters. The intermediary callus was left in place, and the graft was held in position by suturing the overlying periosteum and soft parts tightly over it. The upper and lower teeth were held together with wires for two months. There was primary wound healing and, when the wires had been removed, the fracture was found to be united. Figure 1-B shows the degree of ossification of the intermediary callus and the fusion of the graft with the fragments, four months after operation.

Since the operation was short and simple, and the fracture united promptly, it was decided to apply these principles in similar cases of non-union in other bones. In fractures that have not been the seat of infection, the following general procedure is employed: The bone is exposed, and the periosteum is reflected only from the site to which the transplanted bone is to be applied. The remaining periosteum and callus hold the fragment ends together. If the denuded surface is level, no bone is removed; but it is usually uneven, and any protruding bone is chiseled off, in order to create a satisfactory bed for the graft or grafts. Usually the fibrous intermediary callus is left in place, but in some cases, part or all of it has been removed, with equally satisfactory results. As bony union between fragments and graft is established, the intermediary callus, which was laid down originally by osteogenic cells, reverts to a healthier state, under protection from trauma, and ossifies; or, if a pseudarthrosis is present, the cavity fills with callus which ossifies as motion is abolished. Angulation has occasionally been corrected, and sometimes this step has been facilitated by the removal of part of the intermediary callus. The fracture site is bridged by a broad, strong, whole-thickness, onlay graft or by two somewhat narrower, whole-thickness grafts. Cancellous bone is usually applied to the exposed fracture line on both sides of the graft.

FIG. 2-C

FIG. 2-B

FIG. 2-A

Fig. 2-A: Case 2. Non-union of tibia of one year's duration.
Fig. 2-B: Three months after operation. Fig. 2-C: One year after operation.

The periosteum and soft parts are then reflected and tightly sutured over the transplanted bone. They hold the graft firmly against the shaft and prevent its displacement.

The length of the graft varies according to the fracture and the length of the bone involved. Grafts used for fractures of the mid-shaft of the long bones are usually from 7.5 to 12.5 centimeters long; while those for the end of the shaft are from 5.0 to 7.5 centimeters long, since short grafts fit better there and are easily held in place by the sutured soft parts. The grafts serve, to some extent, as internal-fixation splints. Plaster fixation is carried out for from two to three months, depending on the location of the fracture and the size of the bone; union is nearly always present at the end of that time. The results of such treatment are illustrated by the following cases:

Case 2. F. T., a female, aged thirty-three, had a simple fracture at the middle third of both bones of the left leg, of one year's duration, with union of the fibula and non-union of the tibia (Fig. 2-A). At the operation, an incision was made over the tibia, extending downward 22.5 centimeters from the tubercle. A whole-thickness graft, about 10 centimeters long by 1.5 to 2 centimeters wide, was cut from the upper fragment. The periosteum was then reflected from the medial side of the fragments at the fracture level, and the protruding cortex of the lower fragment was chiseled off to create a level surface. The graft was then inserted into the pocket, with its mid-portion at the fracture level and its periosteum external. Intermediary callus was not disturbed. Cancellous bone was applied anteriorly along the fracture line. The wound was closed tightly, and a cast was applied up to the mid-thigh, with the knee slightly flexed. On removal of the cast at the end of twelve weeks, the fracture was solidly united, and roentgenograms (Fig. 2-B) revealed evidences of repair, including ossification of the intermediary callus. Walking was rapidly resumed, and roentgenograms one year after operation (Fig. 2-C) showed dense ossification of the intermediary callus and fusion of the graft with the fragments.

Case 3. T. W., a male, aged thirty, had a condition in which short grafts could be used to bridge a fracture of the end of the shaft. The fracture of the lower ends of the tibia and the fibula was of six months' standing, and there was comminution and non-union of the tibia (Fig. 3-A). Through a medial incision, the perios-

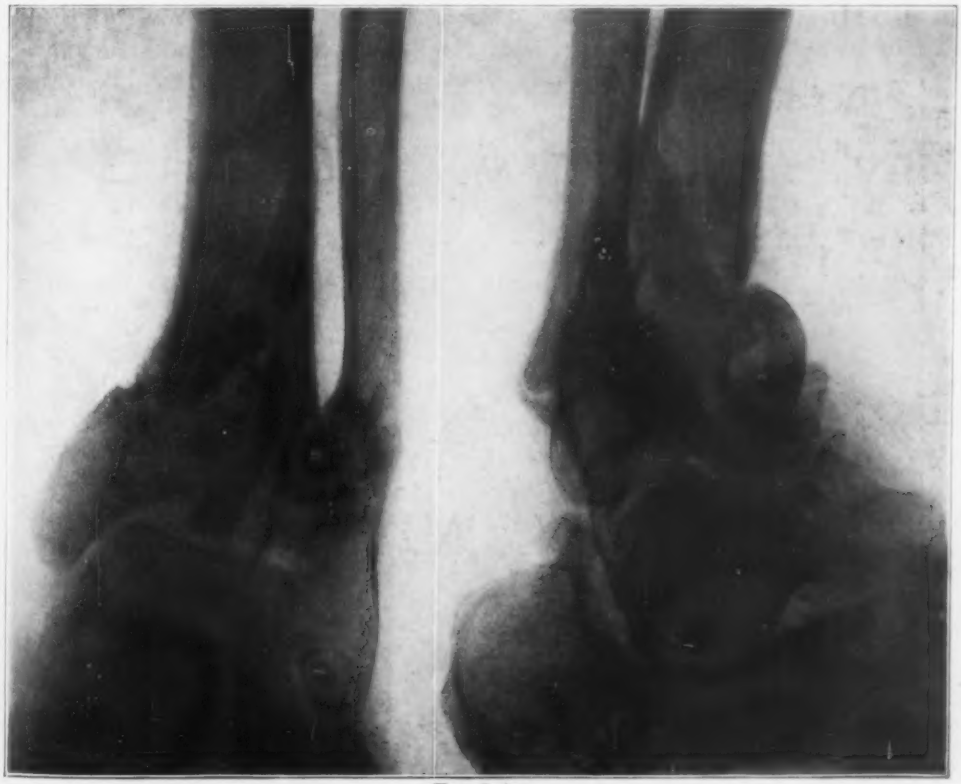

FIG. 3-A

Fig. 3-A: Case 3. Fractures of six months' standing. Comminution and non-union of the tibia are evident.

FIG. 2-C

FIG. 2-B

Fig. 2-A: Case 2. Non-union of tibia of one year's duration.
Fig. 2-B: Three months after operation.
Fig. 2-C: One year after operation.

FIG. 2-A

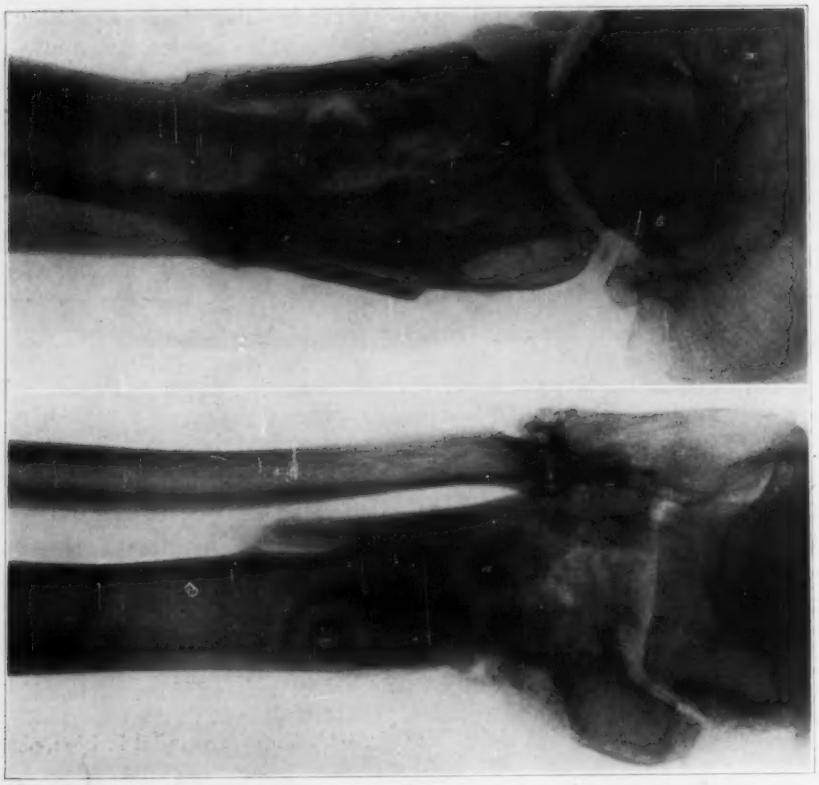

FIG. 3-C

Ten and three-quarters months after operation.

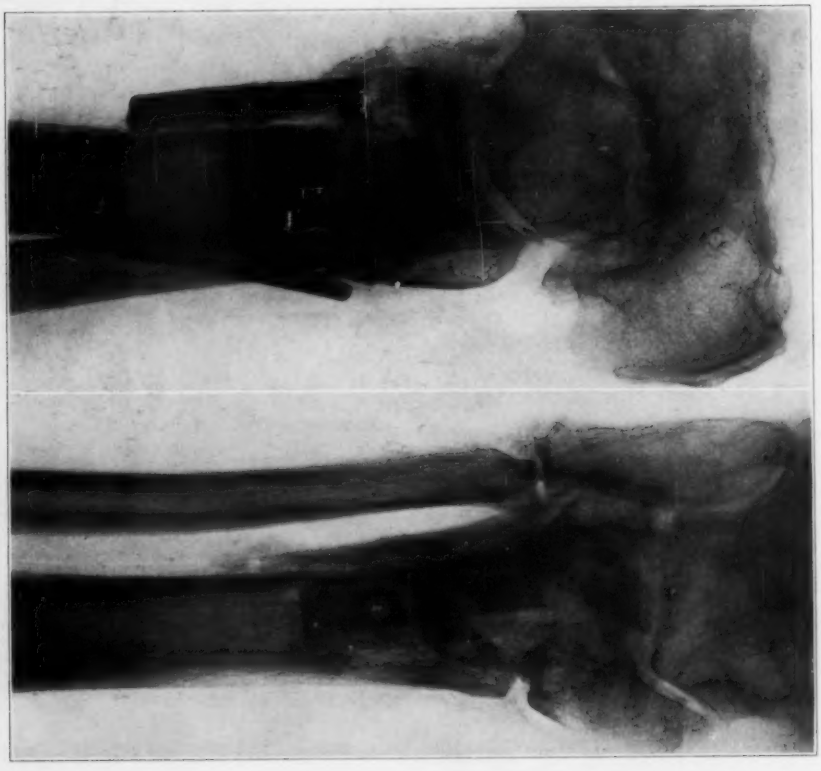

FIG. 3-B

Three months after operation.

teum and callus were reflected from about half of the circumference of the fragments, and the intermediary callus was gouged and curetted out. The fibula was then osteotomized through a lateral incision, and the angulation was corrected by displacing the ankle backwards. Two short grafts, taken from the upper end of the shaft, were laid across the tibial fracture, one anteriorly and one posteriorly, and the soft parts were sutured over them. Twelve weeks later, when the plaster dressing had been removed, there was early bony union (Fig. 3-B). Figure 3-C shows the consolidation ten and three-quarters months after operation.

Case 4. W. W., a male, aged twenty-two, had a fracture of the mid-shaft of the left humerus, which was treated elsewhere the day after injury by open reduction and fixation with a wire, a metal plate, and screws. Non-union followed, and the plate and fragments became angulated. Figure 4-A shows the condition when first seen, five months after the injury. At operation through the old anterolateral incision, the underlying side of the bone was uncovered, and the screws, plate, and wire were removed. The intermediary callus was fibrous, and without removing it, the angulation was easily corrected. A bone graft 12.5 centimeters long, taken from the tibia, was laid across the fracture line in the bed vacated by the plate, and the soft parts were sutured tightly over it. The graft served well as an internal-fixation splint. A body cast, including the left upper extremity, was then applied. When it was removed twelve weeks later, the fracture was united, and roentgenograms, taken four months after operation (Fig. 4-B) revealed ossification of the intermediary callus and bony fusion of the graft with the fragments. One and one-half years later the functional result was excellent.

Case 5. E. T., a female, aged forty-four, had an intermuscular round-cell sarcoma of the lateral aspect of the right upper arm, extending to the elbow. It was treated by heavy irradiation and excision, which included a long segment of the radial nerve. There was irradiation damage to the region, but freedom from recurrence of the tumor. Twenty-three years later, the patient fell and injured the atrophic bones below the elbow. Six months later she appeared at the Clinic, with freely mobile ununited fractures of both bones of the forearm, as shown in Figure 5-A. At operation, a posterior incision was made, and the soft parts were reflected from the back of both bones at the fracture site. A tibial onlay graft was applied to both bones, without removal of

FIG. 4-A

FIG. 4-B

Fig. 4-A: Case 4. Non-union five months after early wiring and plating.
Fig. 4-B: Four months after simple onlay-graft operation.

FIG. 5-C

FIG. 5-B

FIG. 5-A

Fig. 5-A: Case 5. Six-month-old fracture of irradiated, atrophic bones.
Fig. 5-B: Three months after application of simple onlay bone graft.
Fig. 5-C: Two years after operation.

Fig. 5-A: Case 5. Six-month-old fracture of irradiated, atrophic bones.
Fig. 5-B: Three months after application of simple onlay bone graft.
Fig. 5-C: Two years after operation.

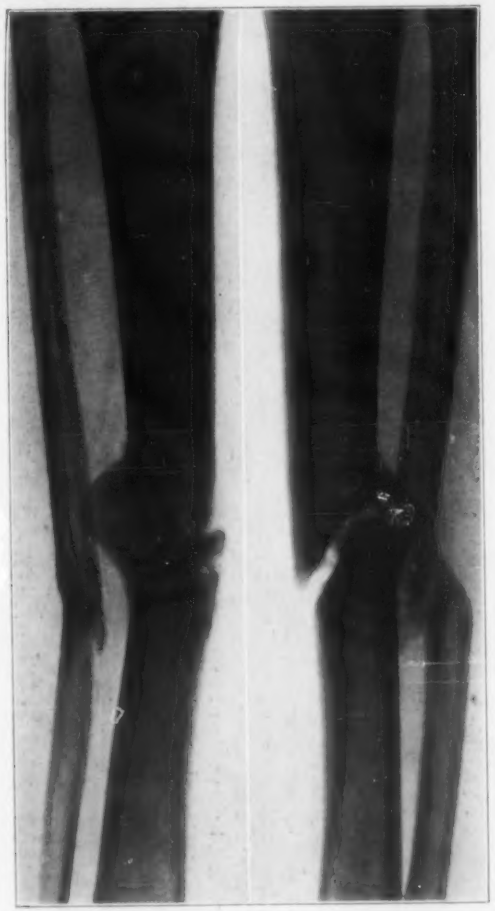

FIG. 6-A

FIG. 6-B

FIG. 6-C

Fig. 6-A: Case 6. Non-union of tibia of fifteen months' duration.
Fig. 6-B: Ten weeks after operation. Fig. 6-C: Thirteen months after operation.

the intermediary callus, and the soft parts were sutured. Despite the irradiation damage, the fracture was found to have united, when the cast was removed three months later (Fig. 5-B). A more traumatizing operation might have precipitated bone and soft-part necrosis and impairment of healing. Two years later, the function of the arm was as good as before the injury, and roentgenograms (Fig. 5-C) revealed complete fusion of grafts and fragments.

NON-UNION OF INFECTED FRACTURES

If a fracture becomes infected, either at operation or as a result of being compounded, and fails to unite, the infection must be healed before an operation for non-union is considered. There is some danger of reactivating the infection, if the operation is performed through the site of the healed wound, with freeing of the fragment ends, removal of intermediary and medullary callus, and fixation of the aligned fragments by an onlay bone graft anchored with screws. In order to minimize this risk, it has been the custom until recently to delay operation for from six to eighteen months, depending on the extent and duration of the lesion and the size of the bone involved; and also to excise scar tissue at a previous operation, if it is extensive. With the use of antibiotics, especially penicillin, it has been possible to shorten this period somewhat.

When the fragments are in acceptable position, the simple type of onlay procedure, here described, has been employed, with avoidance of the old field of infection during the introduction of the graft. The incision is made through healthy skin as far away from the scar as possible, and the soft parts and periosteum are reflected from the bone on the side opposite the scar. If bony prominences are present, they are leveled off; the intermediary callus is never disturbed. The graft is introduced into the pocket, and over it the soft parts are tightly sutured. By avoidance of the field of infection that has healed most recently and with the intermediary callus left undisturbed, the likelihood of infection is reduced to a minimum; thus it was possible, even before the days of antibiotics, to perform the operation at a relatively early date, with a low incidence of infection and a high incidence of bony union, thereby saving the patient many months of disability. Depending upon the case, from one to four months should elapse after healing, before the operation is performed.

Case 6. W. L., a male, aged sixty, fractured both bones of the right leg fifteen months before admission. The tibial fracture was compound and infected, and an open wound persisted on the medial side for thirteen and one-half months. The scar was elliptical, measuring one by four centimeters, and was well healed. Motion was present at the fracture site in the tibia. Roentgenograms (Fig. 6-A) revealed non-union of the fracture of the tibia and union of the fracture of the fibula. At operation, six weeks after wound healing, a whole-thickness graft, nine centimeters long by two centimeters wide, was removed from the upper fragment of the tibia, and the wound was closed. A second incision was made, lateral to the tibial crest at the fracture level and three centimeters away from the scar. The periosteum was reflected from the lateral aspect of the tibia; the protruding callus was chiseled off; the graft was inserted on edge, without removing intermediary callus; and the wound was sutured. No antibiotics were given, and the postoperative course was uneventful. When the cast was removed, ten weeks later, the wounds had healed *per primam*, there was bony callus between fragments and graft, and some ossification of the intermediary callus (Fig. 6-B). Walking was resumed soon afterwards; Figure 6-C shows the consolidation thirteen months after operation.

Case 7. J. G., a male, aged forty-three, was admitted on October 9, 1939, eight months after the fracture of both bones of the right leg, at the mid-shaft. The tibial fracture was compound, and was plated soon after injury. The wound became infected, and the plate was later removed, which left necrotic bone exposed where the plate had come in contact with cortex. On admission, the wound was still gaping and discharging pus. Roentgenograms revealed non-union of the fracture of the tibia and irregularity of the cortex on the anterior aspect, which had been produced by screw holes and bone absorption (Fig. 7-A). At operation, a strip of incompletely sequestrated necrotic cortex, from 5 to 7.5 centimeters long, was chiseled from each fragment, where the bone plate had been anchored. The wound granulated favorably. Five weeks later, the skin was undermined and sutured. The wound remained free from infection and three weeks later was completely healed. Two months afterward, roentgenograms revealed the extensive defects in the fragment ends, created by the fracture of the tibia and the excision. The fracture was still ununited (Fig. 7-B). Three and one-half months after operation, and six weeks after healing, a heavy graft, 12.5 centimeters long, was removed from the other tibia, and, through a posteromedial incision, the posterior surface of the fragments of the tibia at the fracture level were denuded of periosteum and callus. The graft was inserted into the bed, and the wound

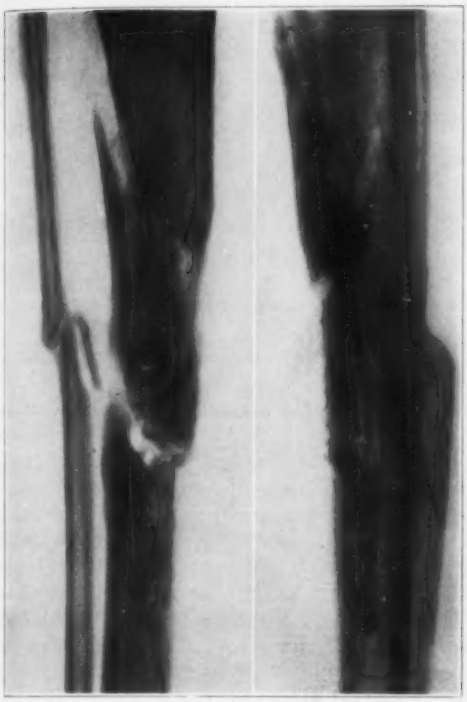

FIG. 7-A

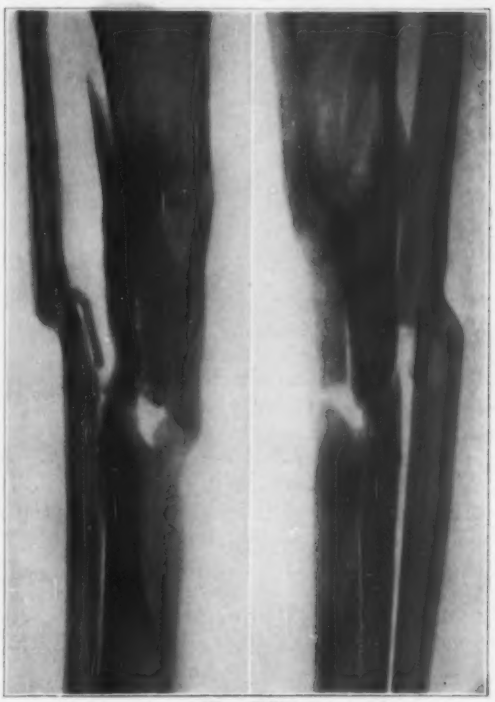

FIG. 7-B

Fig. 7-A: Case 7. Non-union, osteomyelitis, and dead bone eight months after injury and application of plate and screws to tibia.
Fig. 7-B: Three and one-half months after removal of dead bone and six weeks after healing of the secondarily sutured wound.

FIG. 7-C

FIG. 7-D

Fig. 7-C: Three months after application of graft to posterior surface through posteromedial incision.
Fig. 7-D: Eight months after bone-grafting.

was closed tightly. There was healing without infection; and, when the plaster dressing was removed three months afterwards, the fracture had united (Fig. 7-C). Walking on the limb was resumed in four months. Figure 7-D shows the consolidation of the fragments and the graft eight months after operation.

In this case, the long heavy graft served both to bring about union of the fracture and to strengthen the shaft, where it had been weakened by the removal of necrotic bone.

If doubt remains as to whether or not bony union can be obtained by this procedure, without removing intermediary callus or resecting the sclerosed fragment ends associated with pseudarthrosis, it should be dispelled by the following case report.

Case 8. J. S., a male, aged fifty-eight, was admitted ten months after sustaining a simple fracture of the lower third of the left femur.

Because of non-union, the fracture had been fixed six months previously by a steel plate, but the wound had become infected and after two months the plate had been removed. Discharging sinuses were still present and roentgenograms (Fig. 8-A) revealed evidences of non-union, osteomyelitis, sequestra, and screw holes and pinholes in the fragments.

At operation, the dead bone was removed. Penicillin and sulfadiazine were administered, and a plaster spica was worn for three months. At the end of this time, the fracture was still ununited, but the wounds at the fracture site had healed. The limb was placed in a walking caliper splint, but the fracture remained ununited, and, at irregular intervals, sinuses would develop at the site of the lowest pinhole and on the lateral surface of the thigh at the fracture level. Eighteen months after the first operation, the posterior wall of the lowest pinhole was removed, and a sinus and a long scar were excised on the lateral aspect at the fracture level. The wounds were healed two and one-half months later, and in another three and one-half months, there was free mobility and extensive bony callus at the fracture site, as revealed in Figure 8-B. The degree of motion, the wide fracture line, and the sclerosed fragment ends were consistent with pseudarthrosis, rather than with fibrous union. Operation was then performed for the non-union, and penicillin and sulfadiazine therapy were again instituted. A lateral incision, ten centimeters long, was made down to the bone; and the periosteum and soft parts were stripped from the side of the fragments and fracture site, exposing almost two fifths of the circumference of the bone. Two grafts, each two centimeters broad and eight centimeters long, were cut from the left tibia, and spongy grafts were also removed. Bony prominences on the anterolateral and posterolateral aspects were leveled off, and the grafts were applied. Spongy grafts were then placed along the fracture line

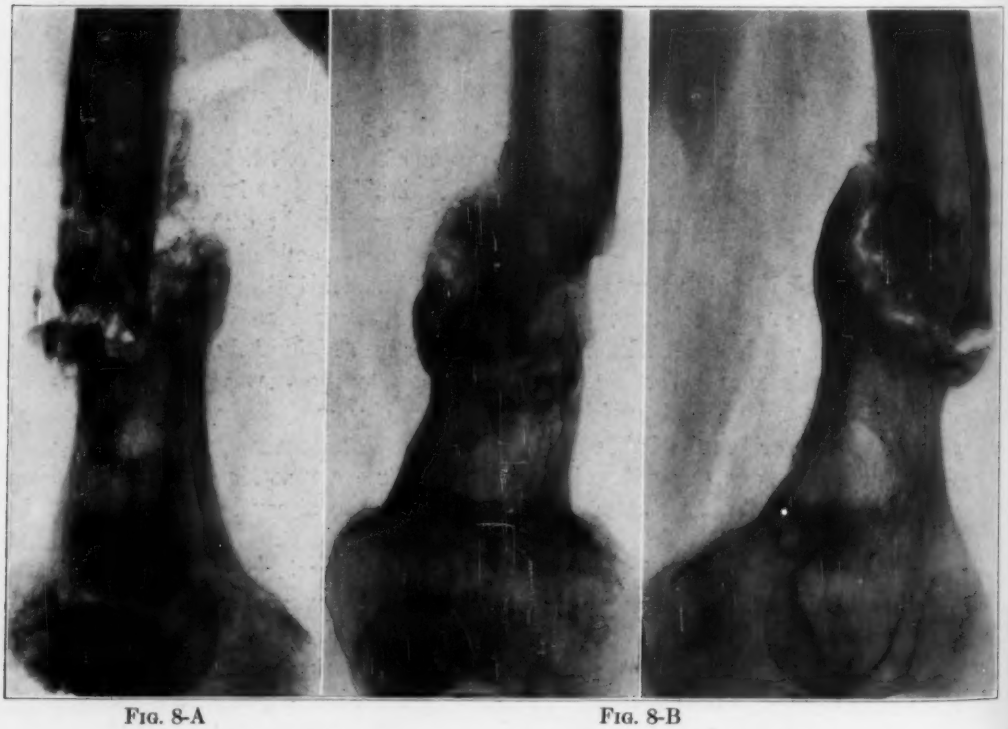

FIG. 8-A FIG. 8-B

Fig. 8-A: Case 8. Infection and non-union, ten months after simple fracture.
Fig. 8-B: Pseudarthrosis nearly three years after injury.

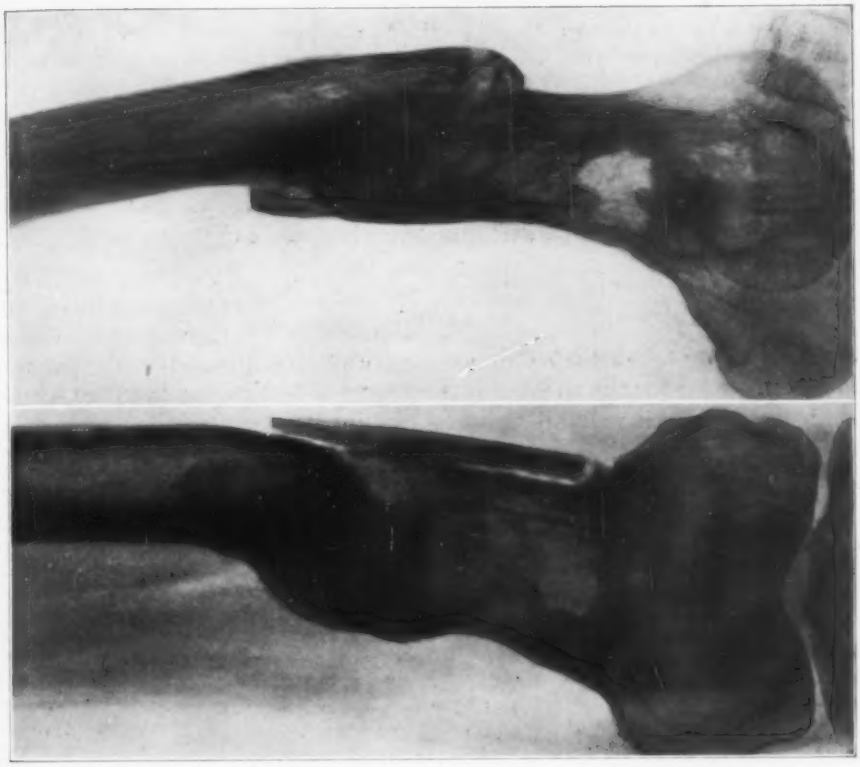

FIG. 8-D
Eleven months after operation. Knee motion of 75 degrees is present.

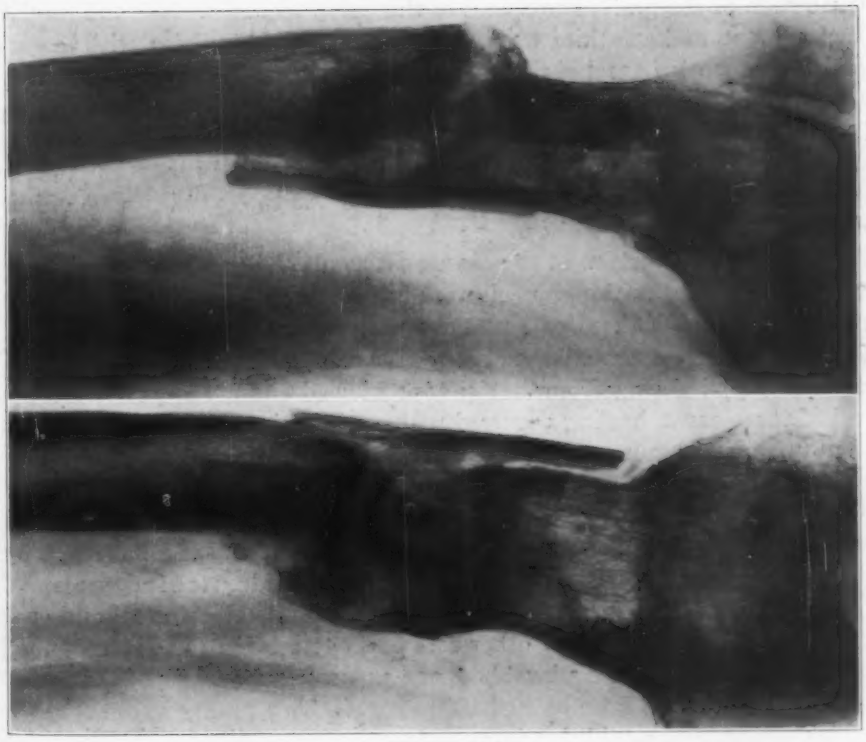

FIG. 8-C
Three months after simple onlay bone transplantation.

between the two cortical grafts. None of the intermediary callus was removed. A plaster spica dressing was then applied, which was left on for three months. When the spica had been removed, there was no motion at the fracture site, and roentgenograms (Fig. 8-C) revealed signs of union between the grafts and fragments and partial filling in by bone along the old fracture line. A caliper splint was worn for three months, and weight was borne on the limb after the fourth month. Union progressed rapidly, and all of the intermediary callus could be seen as spongy bone in six months. Now, eleven months after operation, the callus is more dense, the limb is being actively used, and 75 degrees of motion has been established in the knee (Fig. 8-D).

This good functional result and the absence of wound infection justify the decision not to break down the fracture at operation, in order to correct the considerable degree of displacement of fragments.

DISCUSSION

Delagénière demonstrated that only osteoperiosteal grafts, without anchorage to fragments, should be used for the successful treatment of non-union; however, the operative trauma was extensive, since in all cases the fracture was broken down, the callus was removed, and the fragment ends were denuded in their entire circumference.

Harkins and the author analyzed the results in a series of thirty-nine patients, operated upon by the simple onlay method. These cases comprised 42 per cent. of the ununited fractures of the shaft operated upon during an eight-year period. Satisfactory results with bony union were obtained in thirty-eight cases. Since then, the author has had further experience with forty-nine cases. The distribution of the fractures according to the bone involved was as follows:

Tibia	22	Femur	3	Metatarsal	3
Humerus	7	Pelvis	3	Ulna	2
Mandible	5	Radius	3	Fibula	1

Bony union was obtained with one operation in forty-six of the forty-nine cases. One failure occurred in a three-year-old child with congenital pseudarthrosis of the tibia. The two other failures concerned fractures of the body of the mandible. One resulted from unequal distribution of the graft; two-thirds of this graft was in contact and united with the posterior fragment, and one-third was in contact, but failed to unite, with the anterior fragment, which was poorly immobilized because of so few teeth in the mandible. The other failure was due to infection of the graft as a result of a small opening into the mouth, which was not detected until the end of the operation. The graft was later removed, and the infection was allowed to heal. A similar operation, performed six months later, healed *per primam* and resulted in union of the fracture. This was the only instance of infection and loss of the graft in the entire series.

Infection occurred in thirteen of the cases as a result either of the initial compound fracture or of a previous operation, but all were healed before the operation for the non-union was performed. Six of these patients, five with fracture of the tibia and one with fracture of the femur, were operated upon between one and four months after wound healing, the graft being applied away from the site of previous draining except in the case of the femur. In all of these cases, healing occurred without infection. The other seven patients were operated upon six or more months after healing. There was primary wound healing and union of the fracture in every case except the mandibular fracture previously mentioned.

The rationale of the simple onlay-graft procedure is based on the following: The bone graft, whether in one or more pieces, is relatively strong. It bridges the fracture, splints the fragments, and contains osteogenic cells which survive along its periosteal and endosteal surfaces. Stripping of periosteum and other soft parts attached to one side of the bone, chiseling off prominences to create a level bed, and accurate application of the graft to the fragments set up osteogenesis from both shaft and graft. This results in the throwing out of callus, which ossifies and establishes bony union between the fragments and the graft.

The undisturbed periosteum and peripheral callus of the rest of the circumference serve to hold the fragments together, as does also the intermediary callus when it is not removed. Consequently, displacement of fragments cannot take place. The graft is held so snugly against the fragments by the tightly sutured overlying periosteum and soft parts that it does not work out of place. At the same time, it does not remove the stimulus to fracture healing which is derived from impaction of the fragment ends by muscle pull; nor does the graft fracture, as sometimes happens when a graft is rigidly fixed to the fragments by screws. As union between graft and shaft progresses, the old intermediary callus, which is derived from osteogenic tissue, becomes increasingly protected from the trauma of motion and increasingly subjected to the functional stimulus derived from skeletal support. These forces convert the unhealthy callus into healthy callus, which then goes on to ossification. If pseudarthrosis is present, callus grows into and obliterates the false joint space, where it ossifies. The plaster dressing fixes the fragments for from two to three months and assures maintenance of position.

There has been no opportunity for microscopic examination of the callus during the period of transformation into bone.

There is much additional evidence that a fibrous union or pseudarthrosis may be made to ossify, if the damaging effects of motion on the callus are removed and the reparative stimulus is restored by a bridge of bone. If an ununited fracture of the carpal navicular is treated by the insertion of a bone peg through the interior of the bone across the fracture line, the fracture unites; and what is left of the fibrous intermediary callus, after the peg hole has been drilled, ossifies. Murray has recently reported 100 cases with ninety-six successful results.

Ununited intracapsular fractures of the neck of the femur, with the fragments in good position, have been observed to unite after the introduction of one or two intramedullary bone pegs, without removal of the intermediary callus. The same may happen, if the bone pegs are combined with threaded wires. In a well-performed Putti-McMurray operation for non-union of the neck of the femur, the medial portion of the medially displaced cut end of the distal fragment usually overlaps the under side of the neck, crossing the line of non-union in a manner similar to the short onlay graft employed in non-union of the end of the shaft in other locations. This overlapping and the placement of the fracture of the neck at rest by osteotomy are two important factors in bringing about union of the fracture.

An ununited fracture of the mid-shaft or subtrochanteric region of the femur with angulation of the fragments may be satisfactorily straightened without removal of the intermediary callus; but, because of the danger of recurrence of the angulation in the cast, it may be advisable to fix the onlay graft to the fragments with screws. In that event, we have found that, if the intermediary callus has been left alone, it will ossify promptly, as the graft and shaft unite; the patient may thereby be spared a more prolonged, traumatizing, and bloody operation.

As we have had added experience with this operation, the indications for the use of the simple onlay graft have been extended, until they now include the large majority of ununited fractures of the shaft of long bones. In considering the treatment of such cases, the first question raised is whether or not the result would be acceptable were the fracture united in its present position, or, if necessary, after simple correction of angulation. If the position of the fragments is satisfactory, the simple onlay-graft operation is performed. However, if marked displacement or overriding is present, it is usually best to break down the fracture and then fix the reduced fragments rigidly with an onlay-bone graft and screws, since displacement is likely to occur without fixation. Ununited fractures of both bones of the forearm, with angulation which restricts rotation, should be treated by breaking down the fracture line of one or both bones and fixing the fragments with an onlay graft and screws. If angulation is slight or absent, the simple onlay graft is indicated. In case the

fracture is of the tibia and the degree of lateral displacement is great, warranting reduction, a modified Hoglund sliding-bone-graft operation is usually performed, with an onlay graft applied to ensure union, as well as the intramedullary graft for maintenance of position. This obviates the use of screws for fixation.

SUMMARY AND CONCLUSIONS

1. Ununited fractures of the shaft in which the fragments are in acceptable position have been treated by the application of one or two large bone grafts to a denuded level surface of the cortex across the fracture site, without fixation of graft to fragments with screws or ties, and usually without removal of the fibrous intermediary callus.

2. The grafted bone is held in position by the periosteum and soft parts sutured tightly over it; the fragments are adequately fixed by the remaining callus and attached periosteum, and by the plaster dressing.

3. The graft becomes solidly attached to the fragments, the intermediary callus ossifies, and bony union is established in a high proportion of cases, with a low incidence of infection. There has been no instance of fracture of the graft.

4. If there has been infection of the fracture which has already healed, it is possible to use this technique relatively soon after healing by placing the incision in healthy tissue away from the scar and applying the graft across the fracture line on the opposite side of the shaft. In this way the period of disability may be shortened by several weeks or months.

5. The results of the operation demonstrate the falsity of the teaching that, in order to obtain bony union of this type of fracture, it is necessary to remove the intermediary and medullary callus and to fix rigidly the graft to the fragments.

6. The operation is short, simple, and suitable for a majority of ununited fractures of the shaft. By this operation, the use of screws, plates, and wire is largely avoided.

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BONE GRAFTS

An End-Result Study of the Healing Time *

BY LIEUTENANT COLONEL W. A. BISHOP, JR., MAJOR RICHARD C. STAUFFER, AND CAPTAIN ALVIN L. SWENSON

Medical Corps, Army of the United States

INTRODUCTION

During the past few years, much valuable experience has been gained and considerable progress has been made as a result of the large number of bone-graft operations done in military hospitals. However, the problem of securing early union in a fracture which failed to unite primarily is still far from being an easy one. Consequently, orthopaedic surgeons should not accept too readily the favorable reports which continue to appear in surgical journals. Too many of these articles on bone-graft surgery represent a survey of the literature, and would indicate that any type or modification of a previously described bone-graft operation had proved to be entirely satisfactory.

This follow-up study was initiated in an attempt to work out the indications for the use of the various types and modifications of bone-graft operations, as determined by their respective merits, with the healing time under various clinical conditions being used as a guide.

The survey represents the authors' experience with bone-graft operations at William Beaumont General (Army) Hospital from June 1942 to September 1946. During this period, 580 grafts of the long bones came under our observation; but, due to the nature of a military hospital in wartime, adequate follow-up data are available on only 358 (61.7 per cent.) of this group. Approximately two-thirds of these bone-graft operations were either done by the authors, or were carried out under their supervision or with their assistance. Most of the other cases were transferred to the authors' care during the convalescent period, for further observation and treatment. The composite study appeared more representative and, therefore, more significant as a statistical report. Consequently, no attempt has been made to separate the two groups, because it is the authors' intention to present the problems encountered in bone-graft surgery rather than to report a personal series.

The results obtained by the various types of procedures employed are both interesting and significant. This report is confined to a study of the healing time of the fracture following a bone-graft operation; and was determined by the clinical condition and by the roentgenographic appearance of the fracture line and of the graft. It represents the time interval in weeks up to the point at which sufficient union had taken place so that it was considered safe to allow restricted use of the upper extremity, or full weight-bearing, usually supported by a brace, on the lower extremity.

Before the types of grafts used and the reasons therefor are discussed, it is significant to point out that the majority of these ununited fractures represented the sequelae of serious gunshot wounds of the extremities. In many, there was loss of skin and underlying soft tissue, and often of bone substance. All too often, the comminuted bone fragments were debrided in the early treatment of the wound, resulting in a defect and non-union. Due to the extensive nature of these wounds, considerable scar tissue invariably formed about the fracture ends, resulting in the many unfavorable factors involved in the healing process, associated with diminution of the available blood supply. Full-thickness skin grafts of the pedicle type were necessary in 76 (21.2 per cent.) of the cases which were

* Read at the Annual Meeting of The American Academy of Orthopaedic Surgeons, Chicago, Illinois, January 27, 1947.

followed until the time of healing of the graft. Consequently, the series represents a much more difficult problem in the restoration of bone continuity than would ordinarily be encountered in civilian practice.

During the first six months of the study, only eighteen bone-graft operations were performed, thirteen of these being of the sliding inlay or Albee type. Because of the increased healing period and the failure of union in five (38.5 per cent.), the procedure was changed to the massive onlay graft. Since that time, the inlay graft has been relegated more and more for the treatment of cases of delayed union in which an active healing process was evident.

The application of massive onlay grafts for the long bones proved to be the operation of choice in uncomplicated cases of non-union. The periosteum was carefully stripped from the bone ends to give a continuous sheet, and all fibrous tissue was removed from between the fracture fragments. The ends were freshened to allow good contact, prior to preparation of the bed for the reception of the graft. The medullary canal was opened and cleaned out with a curette to permit endosteal repair.

The graft, measuring seven inches in length and as wide as could be obtained without invading the tibial crest, was usually taken from the opposite tibia. Shorter grafts were used in the upper extremity; the width was determined by the size of the bone being repaired. In the preparation of the graft, all of the cancellous bone on the medullary surface was removed with a saw or chisel, and saved to pack around the fracture site. Additional bone chips were obtained from the upper end of the tibia or ilium, as indicated. The bed for the reception of the graft was prepared by the removal of at least two-thirds of the thickness of the cortex at its thinnest point, to give a flat surface.

Dual bone grafts were first used during 1943, when eight operations of this type were performed. Since that time, an increasing number of the dual-type operations have been performed,—partly because of the type of fracture being treated. However, as will be shown by this study, our indications for the use of the dual-type graft have changed considerably. The bone used for the dual graft was the same width as that for the onlay graft, whenever possible. The maximum graft obtainable from the tibia of the average adult is approximately eleven and one-half inches in length.

Ten cases were seen of fracture of the tibia from which the graft had been removed early in the series. The necessity of a properly fitted, molded leather cuff, to be incorporated in a double-bar, short leg brace prior to the resumption of weight-bearing, cannot be emphasized too strongly. This device effectively eliminated the serious complication of fracture of the donor tibia, which occurred frequently prior to the adoption of this simple precautionary measure.

The problem of closing the periosteum over the graft in those instances in which massive onlay grafts or dual bone grafts are used was solved satisfactorily by making one or more longitudinal slits through the periosteal cuff on the side opposite the graft. By so doing, a periosteal covering may be shifted forward to close over the graft, and the soft tissue may be sutured without tension.

Rigid fixation of the graft by machine-type screws not only is considered advisable, but is imperative if early motion is to be initiated. Many of the patients with uncomplicated bone grafts were being supported by a bivalved cast or by traction, and were receiving physiotherapy for mobilization of the adjacent joints by the sixth week after operation. Unfortunately, follow-up measurements on joint motion were not complete enough to be trustworthy. It was obvious, however, that a good deal of time was saved during the convalescent period; and, in many instances, the permanent disability was altered considerably, as compared to similar types of cases treated by other methods.

One of the authors (A. L. S.) has been using bone plates in conjunction with bone grafts since 1940. In this series, plates were utilized whenever strength and stability was needed, but never as a substitute for a graft. Plates were used in conjunction with three

TABLE I

ANALYSIS OF TOTAL NUMBER OF GRAFTS

Bone Involved	Inlay				Onlay				Dual				Totals			
	Total	Adequate Follow-up	Union	Non-Union	Total	Adequate Follow-up	Union	Non-Union	Total	Adequate Follow-up	Union	Non-Union	Total	Adequate Follow-up	Union	Non-Union
Clavicle	3	3	1	2	4	2	1	1	6	4	4	0	13	9	6	3
Humerus	5	4	4	0	17	9	6	3	59	45	39	6	81	58	49	9
Radius	6	4	4	0	40	19	18	1	36	29	27	2	82	52	49	3
Radius and ulna	0	0	0	0	24	11	11	0	0	0	0	0	24	11	11	0
Ulna	14	9	8	1	38	21	18	3	31	23	23	0	83	53	49	4
Femur	2	2	1	1	60	33	25	8	43	30	28	2	105	65	54	11
Tibia	25	17	16	1	107	49	42	7	60	44	42	2	192	110	100	10
Totals	55	39	34	5	290	144	121	23	235	175	163	12	580	358	318	40

TABLE II

END RESULTS IN TWENTY-THREE FRACTURES OF THE GRAFT

	Humerus			Ulna			Femur			Tibia			Totals			
	Inlay	Onlay	Dual	Inlay	Onlay	Dual	Inlay	Onlay	Dual	Inlay	Onlay	Dual	Inlay	Onlay	Dual	Total
Total number	1	5	1	1	2	0	0	8	2	1	2	0	3	17	3	23
Cases of non-union	0	4	1	1	2	0	0	3	1	1	1	0	2	10	2	14
Average time from fracture to re-graft (*weeks*)		15	9	14	15			19	28	14	16		14	16	22	16
Type of re-graft	0	2	3	0	1	2	0	1	3	0	1	1	0	5	9	14
Average healing time of re-graft (*weeks*)		24	16		30	15		22	18		28	19		26	17	20
Fractured grafts with eventual union	1	1	0	0	0	0	0	5	1	0	1	0	1	7	1	9
Average time from graft fracture to union (*weeks*)	26	20			24	21		24	21		30		26	24	21	24

TABLE III

AVERAGE HEALING TIME ACCORDING TO TYPE OF GRAFT AND BONE INVOLVED

Bone	Inlay		Onlay		Dual		Total	
	No. of Grafts	Average Healing Time (*Weeks*)	No. of Grafts	Average Healing Time (*Weeks*)	No. of Grafts	Average Healing Time (*Weeks*)	No. of Grafts	Average Healing Time (*Weeks*)
Clavicle	1	24	1	22	4	12	6	19
Humerus	4	31	6	15	39	16	49	17
Radius	4	21	18	18	27	17	49	16
Radius and ulna	0	0	11	17	0	0	11	17
Ulna	8	25	18	21	23	14	49	18
Femur	1	26	25	22	28	22	54	22
Tibia	16	24	42	22	42	24	100	23
Totals	34	27 *	121	20	163	19	318	20

*This figure is based upon the exact number of weeks required for healing in each case, rather than upon the average times given in this table.

inlay grafts, twenty-three onlay grafts, and twelve grafts of the dual type. These results have not been tabulated separately, because there was no appreciable difference in the healing time. No fractures occurred in this group of thirty-eight cases.

AVERAGE HEALING TIME OF BONE GRAFTS

Of the 358 cases with adequate follow-up (Table I), 39 (10.9 per cent.) had inlay grafts, 144 (40.2 per cent.) had onlay grafts, and 175 (48.9 per cent.) had dual-type grafts. The average healing time for the entire series of 318 grafts which were followed to union was twenty weeks (Table III). Inlay grafts, which were used under the most favorable circumstances to secure union, were the slowest to heal, averaging twenty-seven weeks; onlay grafts, used in the more favorable type of case, averaged twenty weeks; and the dual-type graft, which was used only in those instances in which slow union was anticipated by other methods, averaged nineteen weeks.

A study of Table III will show a difference in the average healing time for the weight-bearing and non-weight-bearing bones, as would be expected from the criteria set up in this study for the determination of union.

TABLE IV

AVERAGE HEALING TIME OF 318 BONE GRAFTS

Healing Time (*Weeks*)	Type of Graft			Total Grafts		Composite Analysis	
	Inlay	Onlay	Dual	No.	Per cent.	No.	Per cent.
Under 12	0	4	12	16	5.0	16	5.0
12 to 13	1	24	40	65	20.4	81	25.5
14 to 16	2	21	34	57	17.9	138	43.4
17 to 20	6	25	36	67	21.1	205	64.5
21 to 25	6	16	17	39	12.3	244	76.7
26 to 30	9	15	15	39	12.3	283	89.0
Over 30	10	16	9	35	11.0	318	100.0
Total number of cases	34	121	163	318	100.0	318	100.0
Average	27	20	19	20			

TABLE V

ANALYSIS OF 180 CASES OF DELAYED UNION OF BONE GRAFTS ACCORDING TO APPARENT CAUSE

Cause of Delayed Union	Inlay					Onlay					Dual					Total	
	17 to 20 Weeks	21 to 25 Weeks	26 to 30 Weeks	Over 30 Weeks	Total	17 to 20 Weeks	21 to 25 Weeks	26 to 30 Weeks	Over 30 Weeks	Total	17 to 20 Weeks	21 to 25 Weeks	26 to 30 Weeks	Over 30 Weeks	Total	No.	Per cent.
Severe decalcification of fracture fragments	1	0	1	1	3	5	1	2	7	15	12	5	2	3	22	40	22.2
Sclerosis of one or both fracture fragments	1	0	3	0	4	0	1	4	5	10	10	3	5	0	18	32	17.8
Bridging bone defect	1	2	2	0	5	0	3	2	0	5	8	6	1	5	20	30	16.7
Cause undetermined	2	2	2	5	11	3	0	0	0	3	1	1	1	0	3	17	9.5
Postoperative infection without sequestration	0	1	0	0	1	2	2	0	1	5	3	1	3	0	7	13	7.2
Poor apposition of graft	0	0	0	0	0	5	1	1	1	8	2	1	2	0	5	13	7.2
Short graft (three inches or less)	0	1	1	3	5	3	1	1	2	7	0	0	0	0	0	12	6.7
Fracture of graft	0	0	1	1	2	0	0	2	3	5	0	0	1	1	2	9	5.0
Second or subsequent graft following failure	0	0	0	0	0	1	1	2	2	6	1	1	0	0	2	8	4.4
Poor fixation near joint	0	0	0	0	0	1	1	2	2	6	0	0	0	0	0	6	3.3
Total with delayed union	5	6	10	10	31	20	11	16	23	70	37	18	15	9	79	180	100.0
Total with union					34					121					163	318	
Percentage with delayed union	14.8	17.6	29.4	29.4	91.2	16.5	9.1	13.2	19.0	57.8	22.7	11.0	9.2	5.5	48.4		56.6

DELAYED UNION OF BONE GRAFTS

To record in detail the healing time of the various types of grafts in each of the long bones would require too much space, and would not disclose anything more of significance than would a composite analysis, as recorded in Table IV. This tabulation shows that 138 (43.4 per cent.) of the bone grafts had united by the end of the sixteenth week.

On the assumption that certain factors which tend to delay healing of the graft would be evident in those cases requiring seventeen or more weeks to unite, a detailed study was initiated. In some cases, more than one such factor was evident. Only the apparent primary cause of the delayed union in the remaining 180 cases (56.6 per cent.) is shown in Table V.

Local impairment of calcium metabolism accounted for the greatest number of cases of delayed union. Of the 180 cases requiring more than sixteen weeks to heal, forty (22.2 per cent.) presented severe decalcification of the ends of the bones, and thirty-two (17.8 per cent.) had sclerosis of one or both of the major fracture fragments at the time of the bone-graft operation. This group of seventy-two cases of delayed union had the following distribution: seven inlay grafts, which had healed in an average of twenty-seven weeks; twenty-five onlay grafts, which averaged 30.4 weeks for healing; and forty dual-type grafts, used in the cases with more pronounced local disturbance of calcium metabolism, which had an average healing time of only 22.5 weeks.

The third most common cause of delayed union of the graft occurred in cases in which the graft was used to bridge a defect. Without exception, inlay and onlay grafts were not satisfactory when used for this purpose; but, of the 112 dual-type bone grafts used to bridge defects up to five and one-half inches in length, only thirty (26.7 per cent.) failed to have union by the sixteenth week.

In seventeen (9.5 per cent.) of the cases of delayed union, no apparent cause was determined; eleven of these were of the inlay type.

Of the twenty-six infections without sequestration of the graft, thirteen grafts failed to unite by the end of sixteen weeks; but there was no case of non-union without other contributing factors.

Inasmuch as it was our practice to remove at least two-thirds of the thickness of the cortex in the preparation of the bed for the reception of the graft, only thirty-five cases with poor apposition of the graft were collected. Of these, there were thirteen cases of delayed union. The average healing time for the series, when compared with an unselected group of similar grafts of our own, was prolonged by 4.7 weeks.

Fracture of the graft occurred in twenty-three cases (Table II); of the nine which went on to union, all were slow to heal, averaging twenty-four weeks from the time of the fracture.

Poor choice of the type of operative procedure by the use of a poorly fixed onlay graft near a joint accounted for six delayed unions in ten cases. However, there were only four delayed unions in fifty-four of the dual-type operations, done for non-union near a joint.

NON-UNION OF GRAFTS

Failure of the bone graft to unite was encountered in forty (11.2 per cent.) of the cases (Table VI). Fracture of the graft occurred in twenty-three instances, and accounted for fourteen (35 per cent.) of the non-unions. The average time from the fracture of the graft to a subsequent attempt at repair was sixteen weeks.

Infection with sequestration of the graft accounted for twelve (30 per cent.) of the failures. Sclerosis of one or both fracture fragments was considered to be responsible for five failures (12.5 per cent.), and extensive decalcification of the bone ends accounted for an equal number. Poor choice of the type of operative procedure, with inadequate fixation of an onlay graft near a joint, accounted for one failure. Short grafts (less than three inches in length) were responsible for three other instances of non-union.

TABLE VI

ANALYSIS OF FORTY FAILURES OF BONE-GRAFT OPERATIONS

Apparent Cause	Inlay	Onlay	Dual	Total No.	Total Per cent.
Fracture of graft	2	10	2	14	35.0
Infection with sequestration of graft	1	3	8	12	30.0
Sclerosis of one or both fracture fragments	0	4	1	5	12.5
Extensive decalcification of fracture fragments	1	3	1	5	12.5
Short graft (three inches or less)	1	2	0	3	7.5
Inadequate fixation near joint	0	1	0	1	2.5
Total cases of non-union	5	23	12	40	100.0

A second or subsequent attempt to produce union was most successful with the dual type of graft. Of the forty failures, subsequent repair was attempted in thirty-two cases which were followed. Of the ten onlay grafts used, there were six delayed unions and four non-unions. On the other hand, twenty-two dual-type grafts were used at a second or subsequent attempt at repair, with only nine delayed unions and no instances of non-union.

SUMMARY

This study of the end results in the various types of bone-graft operations has permitted a follow-up as to the healing time of 358 of the 580 bone-graft procedures which came under our observation from June 1942 to September 1946. Approximately one-third of the patients studied were transferred from other hospitals, and came under observation during the healing period. No attempt was made to separate the two groups, and the statistical tables represent a composite study.

There were 40 failures (11.2 per cent.). Of the remaining 318 cases, there were 34 inlay grafts with an average healing time of twenty-seven weeks, 121 onlay grafts with union in an average of twenty weeks, and 163 dual-type grafts that had union by an average of the nineteenth week. Of this group, 180 (56.6 per cent.) had delayed union beyond the sixteenth week. The distribution as to type and percentage of the grafts with delayed union was as follows (Table V): inlay, thirty-one (91.2 per cent.); onlay, seventy (57.8 per cent.); and dual, seventy-nine (48.4 per cent.). These end-result figures are particularly significant in view of the different types of clinical conditions for which the three types of grafts were usually employed.

Delayed union of bone grafts, used for the bridging of defects, occurred in five of eight cases in which the inlay type of graft had been used, and also in five of eight cases in which the onlay type of graft had been used; there were three instances of non-union in each group (Table VII). However, of the 112 dual grafts used for the bridging of defects, there were only twenty delayed unions and no failures without complicating factors.

Failure of union near joints was treated very successfully by the dual-type graft, there being only four cases of delayed union and no non-unions without other cause among fifty-four cases (Table VII). All inlay grafts resulted either in delayed union or non-union; and onlay grafts were unsuccessful in four cases and united after delay in six of sixteen cases of non-union near a joint.

Sclerosis of one or both of the fracture fragments was present in forty-seven cases. Of the five inlay grafts used in this type of case, there were four delayed unions and one failure of union. Seventeen such cases had onlay grafts, with ten delayed unions and five non-unions. However, of the twenty-five dual-type grafts employed in the presence of sclerosis, eighteen resulted in delayed union and one in non-union.

Severe decalcification of the fracture fragments was present in forty-nine of the cases

TABLE VII

RESULTS OBTAINED WITH THE THREE TYPES OF GRAFT IN CONDITIONS TENDING TO RESULT IN DELAYED HEALING TIME *

Clinical Conditions	Inlay			Onlay			Dual			Totals		
	Total	Delayed Union	Failure of Union	Total	Delayed Union	Failure of Union	Total	Delayed Union	Failure of Union	Total	Delayed Union	Failure of Union
Bridging of bone defect	8	5	3	8	5	3	112	20	0	128	30	6
Non-union near a joint	4	2	2	16	6	4	54	4	0	74	12	6
Sclerosis of one or both fracture fragments	5	4	1	17	10	5	25	18	1	47	32	7
Severe decalcification of fracture fragments	4	3	1	19	15	4	26	22	1	49	40	6
Failure of previous bone graft, regardless of cause	0	0	0	10	6	4	22	9	0	32	15	4
Fracture of a graft	4	2	2	17	7	10	4	2	2	25	11	14
Postoperative infection without sequestration	2	1	1	12	5	0	12	7	0	26	13	1
Postoperative infection with sequestration	1	0	1	4	1	3	8	0	8	13	1	12
Short graft (three inches or less)	10	5	2	11	7	3	0	0	0	21	12	5
Poor apposition of graft	0	0	0	26	8	2	9	5	0	35	13	2

* This is a complete tabulation; more than one factor is evident in a number of cases, and the figures represent the total number involved.

studied. Four inlay grafts resulted in three cases of delayed union and one of non-union; nineteen onlay grafts resulted in delayed union in fifteen and failure in four; and, of the twenty-six dual-type grafts used in this condition, there were twenty-two delayed unions and one non-union.

A second or subsequent graft after an initial failure also resulted in slow union. In this group, there were ten onlay grafts with six delayed unions and four repeated non-unions. However, of the twenty-two dual grafts used after a previous failure, there were only nine delayed unions and no non-unions.

Fracture of the graft occurred in twenty-five of the cases. Of these, fourteen appeared to be the direct cause of non-union, and eleven healed in an average of twenty-seven weeks from the time of the fracture.

Postoperative infection was encountered in thirty-nine cases. In thirteen of these, there was sequestration of the graft; and failure of union occurred in all but one. In the twenty-six cases without sequestration, delayed union occurred in thirteen cases, and in one other case a fracture of the graft failed to unite.

Short grafts are seldom, if ever, indicated. Of the twenty-one grafts which were three inches or less in length, twelve resulted in delayed union and five in non-union.

Failure to provide a flat surface for the reception of the graft was obvious in thirty-five cases, there being thirteen delayed unions and two failures in the series.

The use of plates in conjunction with bone grafts was employed in three inlay grafts, twenty-three onlay grafts, and twelve grafts of the dual type. The healing time was the same, with or without the use of the plate. There were no fractures in this group of thirty-eight cases, and early mobilization was possible in all instances.

Adequate fixation of the graft with screws will permit early mobilization of the adjacent joints. When this routine was followed, it resulted in marked reduction of the length of the convalescent period, and often in reduction of the proportion of patients with permanent disability, as compared to similar cases treated by other methods.

CONCLUSIONS

The ten rules in bone-graft surgery for the early return of function are as follows:

1. Inlay grafts (Albee type) should be used only in cases of delayed union, where an active healing process is already present.

2. Onlay grafts are the choice in the uncomplicated cases of non-union of the long bones.

3. Dual-type grafts are indicated as follows: (a) to bridge a defect; (b) to repair non-union near a joint; (c) in the presence of marked decalcification of the ends of the bone; (d) when there is sclerosis of one or both of the major fracture fragments; and (e) when a previous bone graft has failed.

4. The removal of at least two-thirds of the thickness of the cortex in the preparation of the bed for the reception of the graft will result in earlier union and fewer failures.

5. Careful stripping of the periosteum to give a continuous sheet at the time of exposure and the judicious use of one or more longitudinal slits in the periosteal cuff on the side opposite the graft will allow the soft-tissue covering of the bone to be shifted forward and to be sutured without tension, when onlay or dual grafts have been used.

6. Short grafts are seldom, if ever, indicated. Onlay grafts should approximate seven inches, as nearly as the particular bone involved and the site of the fracture will permit.

7. A second or subsequent attempt at repair should be made without delay, following the fracture of a graft.

8. Early mobilization of the involved extremity will reduce the temporary or permanent disability, or both.

9. Rigid fixation of the graft is mandatory, if early supervised use of the extremity is to be practised.

10. Plates should be used in conjunction with bone grafts when additional stability is needed, but should never be used as a substitute for the proper type of graft.

NOTE: The contents of this paper do not necessarily represent the policy of the U. S. Army Medical Corps. The ideas expressed are those of the authors, all of whom have resumed civilian practice.

DISCUSSION

MAJOR GENERAL NORMAN T. KIRK, WASHINGTON, D. C.: I am delighted to have the opportunity to discuss these excellent papers on the various types of bone grafts in the treatment of non-union. Different approaches as to procedure and means for the use of internal fixation have been presented, as well as an excellent follow-up report of a large number of bone grafts. End results in regard to failure of union and time of healing required, based on the method of graft used as well as on the various bones involved, have been shown.

Dr. Phemister prefers the onlay type of graft with no fixation except soft-tissue closure; and, in the beginning of his paper, he states that this type of procedure is one for the treatment of selected types of ununited fractures. The results he shows are excellent. Possibly the type of case for this method is limited to those shown by the author, as they would appear not to require firm fixation of the graft to assure stability of the fragments after the plaster had been applied. It is questioned whether this method would succeed when there was marked loss of substance or loss of stability at the fracture line, preceding the operative procedure. I am sure there is complete agreement with Dr. Phemister that, with decrease in the stripping of soft tissues from the fragment ends and in the extent of the operative procedure, there will be less disturbance to the circulation to the part, less shock, fewer deaths, and less chance of infection. It is believed that a graft to the external surface of the tibia, under a covering muscle, as he has applied it, is a superior method to that of placing the graft on the inner surface, when consideration is given to blood supply to the graft from the soft tissue covering it. However, I cannot agree with Dr. Phemister—and war experience clearly demonstrated this—that a graft should be done at any time in any extremity when a sinus is present, connected with the original fracture, or when there is scar in the extremity that might break down because of an operative procedure in that extremity.

Dr. Bishop and his associates report their observations with 580 bone grafts, which came under their care in one Army General Hospital in the war years of 1942 to 1946. Their statistical analysis gives a follow-up on 358 of these cases and is a most interesting one, showing the healing time, the failures, and other statistical data, as applied under different conditions to different bones by the presently accepted methods of bone-grafting. This represents a great many bone grafts for the correction of non-union and lost substance, following fractures in long bones, to be observed by any group in a four-year period.

These surgeons feel that rigid fixation of the graft to its bed by metal screws is essential, particularly if early motion is to be instituted,—beginning at the end of six weeks, on an average. One of the group supplemented the graft with a steel plate and screws in thirty-eight of these cases, to add strength and stability. There was no apparent difference in the healing time in these cases, and there were no fractures in this group.

The sliding inlay type, used by this group at first, was soon discarded, because it was felt that union did not progress so rapidly as might be expected by the use of the massive onlay type of graft. Thus the method devised by Albee was discarded; and the massive onlay type, used and publicized by Campbell, was adopted. There were thirty-nine cases in which the inlay-type graft was used, with five failures, or a percentage failure of 12.8. In doing an onlay-type graft, a massive graft was cut and about two-thirds of the thickness of the cortical shaft forming the graft bed was removed. This placed the graft in contact with the medullary blood supply of the involved bone ends. This is a modification of the Campbell method, as Campbell removed only sufficient bone to make a flat bed to receive the graft. Phemister does not recommend the removal of as much bone as this in the formation of a graft bed. Peterson reported several cases of bone grafts to the femur before this Society in 1943, using this method of having the graft bed in contact with the medullary blood supply. He believed that this hastened union. In this I agree. Johnson pointed out, in experiments on dogs some years ago, that medullary blood supply was essential for union.

In this series, 144 cases are reported in which this method was used, with twenty-three failures, or a failure of 16 per cent. This method involves a more extensive surgical procedure than that advocated by Phemister, and interferes with circulation to the bone at least to 50 per cent. of its circumference.

Dual grafts, developed by Boyd, were first used by this group in 1943; and apparently soon became the most popular method to meet the situation then confronting these surgeons in caring for non-union. It was the method of choice of these authors to bridge defects; to correct non-union adjacent to joints; in atrophic and sclerotic bone; and when a previous graft had failed. In this series 175 cases are reported, with twelve failures, or a failure of 7 per cent. Failure to obtain union, then, when the type of graft used was the only factor considered, occurred more often in the massive than in the dual-type graft. Likewise, the adjudged healing time averaged nineteen weeks with the dual graft, twenty weeks with the onlay graft, and twenty-seven weeks with the inlay graft, a general average of twenty weeks.

These are most interesting observations on success and failure as regards various types of grafts used, although many other factors are considered to have a bearing on healing time and success of union.

More interesting to me than the statistical studies are the successful results,—the union secured. There were a total of forty failures, or 11.2 per cent. in this series. Yet the indication for bone-grafting was for bridging bone defects of from one to five inches in 128 cases, marked decalcification of fracture fragments in 49, and sclerosis in 47. There were undoubtedly soft-tissue loss, moderate to severe chronic healed osteomyelitis, and circulatory insufficiency; and extensive scarring surely followed those gunshot wounds which required preliminary excision and adequate skin coverage before bone-grafting could be attempted. I wonder in how many of these 358 cases the fracture had been compounded and comminuted by the original injury or by the surgeon first treating the case, and how many of them had been infected, either slightly or severely.

Fracture of the graft accounted for fourteen or 35 per cent. of the failures. This may be attributed, from a practical standpoint, to improper mobilization or protection; or again it might be the fault of the patient, and result from a condition over which the surgeon had little control. "Pilot error" accounted for 7.5 per cent. of failures,—the graft was three inches or less in length. Infection was responsible for only twelve or 30 per cent. of the cases which failed.

It is interesting to compare the low incidence, twelve cases or 3.3 per cent., of graft loss from infection in this series of 358 cases in World War II with a loss of twenty-two cases, or 17 per cent., which occurred in 129 cases reported by me in 1924 from World War I. Chronic osteomyelitis was the rule in the majority of cases in World War I following compound fractures. The control of infection required months of treatment, and this resulted in non-use and atrophy of muscles and bone. Bone-grafting was not attempted until the wound had been healed six months or more, with the revision of the wound scar tissue and its removal and skin coverage. In this War better primary surgery, assisted by sulfonamides and penicillin, as Dr. Phemister has pointed out, reduced osteomyelitis to the minimum and permitted definitive surgery several months earlier than in World War I. The onlay and dual methods of grafting were unknown at that time. Henderson used and taught the use of the massive graft, which was the graft ordinarily used.

The only failure in twenty-eight bone grafts for non-union following simple fractures, or in which there had been no previous infection reported by me at the same time, was one "fishtail" graft in an ulna, which was too small. This was the "pilot error" again. There were no infections in these twenty-eight cases. Kangaroo tendon and catgut were used to secure grafts in those days, following the teaching of Albee. No screws were used in my series. Kangaroo tendon or catgut in this devitalized tissue and bone frequently acted as a foreign body and caused failure. For that reason grafts were made self-retaining, wherever possible.

It is felt that the preparation of the graft bed in regard to the soft tissue and the skin covering of the extremity is more important than the selection of the graft to be used, and that this must be accomplished before the graft is attempted.

I am sure that Dr. Phemister is correct when he states that the incision through which the graft is done should be in tissue undamaged at the time of the injury, if this is possible. Too often, in war wounds and in severe compound fractures, it is not possible.

In selecting the type of graft to be used for non-union and loss of substance in shafts of long bones, in the diaphysis, and in flat bones, as has been pointed out in these papers, one must consider certain factors and others which I want to discuss. In a paper before The American Orthopaedic Society last year, Abbott recommended the use and showed the advantage of iliac bone as a graft in the diaphysis of long bones, for non-union in flat bones and cortical bone, and for non-union and lost substance in the shafts of long bones. I heartily agree, from my present experience. We had felt, until this analysis was made, that the massive onlay-type graft was the graft of choice for non-union, with or without lost substance, in the femur and humerus and, in a modified form, in both bones of the forearm; and that it should be fixed securely with screws and should be in contact with the medullary blood supply. We felt that this graft should be of sufficient size to give stability as an internal splint when applied, that it should be supplemented with cancellous bone from the tibia or ilium; and that in the bones of the leg an inlay-type transplant from the good leg, made self-retaining, was the procedure of choice and far superior to the sliding graft in a bone, which disturbed its medullary blood supply. Sclerotic bone presents a problem, particularly in the typical pseudarthrosis. Personally, I look upon sclerotic bone as scar tissue of bone in which there is no blood supply and, frequently, through which no new blood channels can be formed. I believe that its removal is indicated except for a supporting bridge to a graft, and that the scar tissue between the sclerotic ends should be removed for the same reason. In bone which is atrophic from lack of blood supply, infection and non-use frequently produce a cortex no thicker than an eggshell, through which one can easily push a hemostat. The medullary canal is filled with fat. In this type of bone it is impossible to fix an onlay graft with screws, as there is not enough cortical bone to hold. Neither can an inlay be made into such bone and secured there. A dual-type graft must be used to secure the screw to the fragments of the bone end. This is the type of bone in which an intramedullary graft can be used, after the ends of the fragments have been removed. Extensive stripping of periosteum is, therefore, not necessary; it does not interfere with medullary circulation, nor does it deprive the bone fragments of the circulation that is present at the time of surgery.

Probably we shall have to change our opinion as a result of the experience in these papers, and use the dual rather than the onlay graft for loss of substance and in meeting the problem presented by sclerotic and atrophic bone. I have had no personal experience with the dual-type graft. I still feel, however, that all scar tissue between bone ends should be removed before a bone graft is applied, unless that scar tissue is needed for stability, in that it limits the blood supply to the graft and to the fragments.

I am sure that the papers presented will give all of us new thought as to types of grafts to be employed when we are confronted with non-union and lost substance in long bones.

DR. GEORGE O. EATON, BALTIMORE, MARYLAND: Dr. Phemister has presented a very simple method for use in cases which are in reality very simple bone-grafting problems, in that alignment at the site of non-union was satisfactory and needed no correction. This implies minimum operative trauma and, consequently, minimum disturbance of the local circulation. The cases selected for this type of procedure are only 42 per cent. of the total number needing bone-graft procedures. In the ten cases which he presents today and the eighty-eight cases which he refers to, the percentage of successful operations is almost 100. These results are testimony to the efficiency of the local circulation and to the relative lack of circulatory embarrassment due to operative trauma. I doubt very much if the percentage of unions would have been reduced by screw fixation of the graft to the host. I should like to ask Dr. Phemister what method he uses for the more difficult bone-grafting problems.

Dr. Bishop and his colleagues have given us their results and conclusions, based on a follow-up study of 358 cases in which various types of bone-graft operations have been done by surgeons of variable ability. One-third of their cases were done elsewhere, and were observed by the authors during convalescence. I believe that their conclusions, based on so large a series, should form a reliable guide in estimating the relative chance of a successful bone-graft operation by the average surgeon. It is unfortunate that the types of fracture could not have been classified as simple and compound. F.C.C. is a well-known term to many of us, meaning fracture, compound and comminuted; the fracture was usually due to injury by high-velocity missiles. This type of fracture was seen chiefly in combat troops in battle. Combat troops at rest or in training and all other troops usually sustain simple rather than compound fractures. F.C.C. carries with it a variable, but often very extensive, degree of soft-tissue injury, including impairment of local circulation. The factors of damage to circulation and prompt and efficient immobilization determine, more than any other factors, the rate of healing of fresh fractures and of bone grafts. We have prompt union, delayed union, and non-union of bone grafts, just as we do of fresh fractures; and the factors which determine the rate of healing are basically the same in both instances. A most important prerequisite to successful bone-grafting, particularly on subcutaneous bones, is the removal of scar tissue overlying the bone and its replacement by a thick, healthy pedicle graft. Many of us have seen union take place while we were waiting for the pedicle graft to mature sufficiently to operate through it. Complete and sudden disruption of circulation in bone leads to aseptic necrosis; partial reduction of blood supply to bone results in atrophy and demineralization. Greenberg and Mohamed have produced delayed union of fractures experimentally in rats by partially ligating the femoral arteries. Activity and use of a limb with an ununited fracture, but protected by a suitable brace, is often indicated preparatory to grafting, so as to rejuvenate a sluggish circulation. In Dr. Bishop's series, the highest percentage of failures occurred where there was marked decalcification of the fracture fragments.

Dr. Bishop's paper is a very valuable contribution. Not many of us will be able to report follow-up studies on 358 cases of bone grafts, particularly in the types of fractures seen in war surgery. He is to be congratulated on his foresight in recognizing the value of such a study and in successfully carrying it out under the difficulties presented by military practice in wartime.

DR. D. B. PHEMISTER (closing): With reference to the preparation of the bed for the graft, some of the speakers emphasized the advisability of cutting away a good deal of the peripheral portion of the fragments. Personally, I strip the periosteum thoroughly, leaving a well-denuded surface; but I do not remove any more cortex than I have to, in order to create a level bed for the graft. The stimulus of removing the periosteum is enough to incite callus formation from the cortex, and the graft itself also forms callus. It is the combination of the callus from the two which brings about union between the fragments and the graft.

The advisability of using internal fixation in order to obtain early motion was mentioned. I believe that I have stretched a point in prolonging the immobilization during the period of healing of fractures operated upon by this method, because, in two patients who were confined to bed as a result of additional injuries, I did the operation without applying a cast at all, and the fragments united just as promptly as in the cases in which casts had been applied. If some of the patients with leg fractures were allowed to go on crutches without cast fixation, they would probably obtain bony union, and joint motion could be restored at an early date. However, I do not advise this as a routine procedure.

Dr. Eaton asked what technique I favor in case it is necessary to break down the fracture line and realign the fragments. I usually use the same technique which is generally used,—namely, the application of

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CARTILAGE AND CHONDROITIN SULPHATE

II. Chondroitin Sulphate and the Physiological Ossification of Cartilage*

BY BENGT SYLVÉN, M.D., STOCKHOLM, SWEDEN

From the Department of Radiopathology, Radiumhemmet, Stockholm

The normal endochondral and perichondrial ossification processes are characterized by degeneration and subsequent digestion of cartilage, as it is replaced by bone. Leaving the well-known morphological descriptions and turning instead to the actual happenings and main factors governing the ossification process, we are faced with complicated chains of cooperating events. The closed structure of the preosseous cartilage is suspended, and the same cartilage is confronted with a multitude of new biological factors, such as the primitive bone marrow with its fibroblasts, capillaries, and numerous enzymes. The destruction of cartilage, so easily brought about by the cells of the primitive bone marrow, is probably due to the action of proteolytic enzymes, which have not yet been demonstrated. Concurrently, lime salts are laid down by the action of osteoblasts, which probably produce alkaline phosphatase, a group of enzymes playing an important role in bone formation and calcification [11]. Histochemical investigations show that the intercellular medium of normal hyaline cartilage (tracheal or bronchial) is devoid of alkaline phosphatase [1, 5]; but, in places where ossification is going to occur, large quantities of this enzyme have been demonstrated [1, 9].

Incomplete quantitative data as to the changes of chondroitin sulphate during the ossification and calcification of cartilage are to be found in the literature. Logan stated that calcification of cartilage was preceded by a loss of organic sulphates,—namely, a loss of chondroitin sulphate. Thus he found a decrease in the acid constituent of cartilage, and this was considered to favor the precipitation of the inorganic salts. The same results were reported by Hass, who analyzed the content of chondroitin sulphate in human costal cartilage. He noted a gradual depletion of the ester sulphate with increasing age, and thought the mechanism for the maintenance of the intercellular matrix to be deteriorated. Hass made the interpretation that "...maintenance of a high level of chondroitin-sulfuric acid is a device by which cartilage is protected against calcification".

The investigations mentioned are of special interest, and pertain directly to the histochemical results to be presented.

Some young rats (from one to twenty-one days old), rat embryos (25 and 34 millimeters in length), and one human foetus (82 millimeters in length) were employed in this study. Sections from *Anlagen* of occipital bone, mandible, nose, hands, legs, feet, and fingers were used. After fixation in basic lead acetate (4 per cent. aqueous solution) or in formaldehyde solution, parts of the skeleton were sectioned without previous decalcification. Staining was performed with toluidine blue (0.1 per cent.) in alcohol solutions of different concentrations (1, 30, 50, 60, and 80 per cent.), according to the technique described previously by the author [13, 14]. All sections were of the same thickness (5 microns) and were treated in exactly the same manner. Thus, according to statements in the first portion of this report [15], the content of chondroitin sulphate could be estimated approximately, and the occurrence of this substance could be localized histochemically.

The present observations are recorded in Table I; and a comparison is made with available data on the occurrence of alkaline phosphatase in the corresponding tissues, according to other investigators.

From the results in Table I, the following conclusions are fairly evident: 1. During the early embryogenesis of cartilage, the gradual increase in content of chondroitin sulphate

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TABLE I

ESTIMATED AMOUNTS OF CHONDROITIN SULPHATE AND ALKALINE PHOSPHATASE IN THE INTERCELLULAR MATRIX OF CARTILAGE, OSSIFYING CARTILAGE, AND BONE

Developmental Stage and Type of Ossification	Type of Tissue	Approximate Amount of Chondroitin Sulphate According to the Present Investigations	Approximate Amount of Alkaline Phosphatase According to Other Authors
Embryonic	General mesoderm	None (or slight)	Large [5, 9]
	Precartilage	Just demonstrable	Large [5, 9]
	Protochondrium	Large, *increasing*	Rapid decrease [9]
	Perichondrium	None (or moderate)	Moderate (varying) [5, 9]
Endochondral Ossification	"Hypertrophic" cartilage (vesicular layer)	Large, *decreasing*	Increasing [9]
	Calcifying cartilage	None	Large [9]
	Embryonic bone marrow and osteoblasts	None	Large [9]
	Newly formed endochondral bone	None	Large [9]
Perichondrial Ossification	Diaphyseal perichondrium at beginning of ossification	None	Large [9]
	Periosteal osteoblasts	None	Large [9]
	Newly formed perichondrial bone	None	Large [9]
Intramembranous Ossification	Preosteal osteoid	Moderate	
	Osteoblasts	None	Probably large
	Newly formed bone	None	
Adult	Cartilage	Large	Absent [1, 5, 9]
	Perichondrium	None	
	Bone	None (see text)	Absent [1]
	Periosteum and endosteum (osteoblasts and capillaries)	None	Moderate [1]

is accompanied by a corresponding decrease in alkaline phosphatase. 2. Normal adult hyaline cartilage, which does not ossify, contains in its intercellular matrix a large amount of chondroitin sulphate, but little or no alkaline phosphatase. 3. The normal embryonal ossification process is characterized by a rapid local disappearance of chondroitin sulphate, and concurrently by the appearance of large amounts of alkaline phosphatase.

With the metachromatic staining technique, the author has usually not been able to demonstrate any chromotropic substance in the perichondrium or periosteum (Table I). Newly formed embryonic bone (both endochondral and perichondrial) and adult bone are free of histochemically demonstrable ester sulphates in the calcified matrix. This finding is in accordance with that of Meyer, who, by chemical analysis, could not verify the conception of earlier authors [4, 8] as to the supposed content of chondroitin sulphate in spongy bone.

The findings of the present histochemical investigation support the statements by Logan and, to some extent, those by Hass, previously referred to. These findings, however, give more information as to the actual site of depletion of chondroitin sulphate than those by Logan. Obviously, the content of chondroitin sulphate is diminished in the vesicular layer of the "hypertrophic" cartilage, and almost all chondroitin sulphate has disappeared from the intercellular medium of the degenerating cartilage in places of osteoblast activity. Thus, it seems most probable that *removal of the acid chondroitin sulphate is a prerequisite for the action of the bone-forming osteoblasts.* Corresponding observations have been made in intramembranous ossification (Table I).

The manner in which the removal of acid substance is effected requires some discussion. We should consider the possibilities of more rapid absorption or inhibited production

of chondroitin sulphate, but this probably occurs by disintegration of the ester sulphate in question. It was emphasized in a previous paper [15] that the native chondroitin-sulphate molecule presents a remarkable susceptibility to weakly alkaline reactions. A shift in hydrogen-ion concentration to the alkaline side seems to be sufficient to depolymerize the chain molecule, which would explain the histochemical observations. Several other factors might also be involved—namely, proteolytic enzymes and other enzymes—but lack of additional data prevents further discussion.

Avoiding all teleological allusions to the "protective action" of chondroitin sulphate [3], we may summarize the present results as follows: The embryonic hyaline cartilage contains an acid intercellular substance. One of the first demonstrable changes, when ossification and calcification are initiated, is found to be a disappearance of this acid material. After the removal of chondroitin sulphate, the specific osteoblast activities are exerted. The precipitation of lime salts is directed by alkaline phosphatases, which demand an alkaline reaction for hydrolytic activity [1, 9, 10, 11]. The increased alkalinity is probably effected by the primitive bone marrow with its blood vessels. The same mechanism seems also to be sufficient for explaining how the chondroitin sulphate is removed from the preosteal cartilage.

As to the "oversimplified interpretation" of Hass, actually the chondroitin sulphate of cartilage can not be regarded as a protective mechanism against calcification. With reference to the previous conceptions [15], we have to retain the opinion that chondroitin-sulphuric acid, by its acid reaction, in a general way favors some enzyme reactions, while inactivating other enzyme systems. Furthermore, the intercellular medium of normal adult cartilage is devoid of alkaline phosphatase [1, 5, 9], and thus the precipitation of lime salts is prevented.

A decrease in the content of chondroitin sulphate is also noted under physiological conditions [15], in amianthoid degeneration, and in fibrous metaplasia of cartilage [2, 12]. This the author has been able to confirm from his own material. Such conditions are not necessarily combined with calcification.

SUMMARY

By means of the metachromatic staining technique, the distribution and approximate amount of chondroitin sulphate in embryonic cartilage were studied during the ossification process. Previous statements by Logan have been corroborated, and additional data are presented. Thus the ossification of cartilage is evidently *preceded* by a loss of chondroitin sulphate, which begins in the "hypertrophic" vesicular layer of cartilage. In places where osteoblast activity is actually exerted, all chondroitin sulphate has usually disappeared. The disintegration of the ester sulphate is probably effected by a shift in hydrogen-ion concentration, by enzyme action, or both. From a morphological point of view, the ingrowing blood vessels and fibroblasts of the primitive bone marrow carry the active mechanisms which are transferred to the intercellular medium. The destruction and removal of the chondroitin sulphate seems to be a necessary link in the chain of events producing an alkaline medium, which is a prerequisite for the action of alkaline phosphatase.

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DISCUSSION

Bone Grafts

(*Continued from page 972*)

onlay grafts fixed with metal screws. On the tibia, a modified Hoglund operation, with sliding intramedullary and onlay grafts, gives excellent results.

Dr. W. A. Bishop, Jr. (closing): General Kirk made the statement that, in the latter part of our series, we discontinued sliding inlay grafts. I do not want to leave that impression. Due to the type of condition encountered in the series, and to our experience with the prolonged healing time of the inlay graft in all but the delayed unions in which an active healing process was present, that type of graft was considered to have few indications. As to the dual-type graft versus the massive onlay graft, we wish to repeat that the massive onlay graft is the choice in the uncomplicated cases of non-union of the long bones. However, as was borne out by the statistical reports, the dual graft should be used for the earliest return of function, under the circumstances listed in the Summary.

I am sorry that we are unable to tell you the number of compound, comminuted fractures in the series. As a general statement, in the early days, there were an estimated 30 per cent., but, near the close of the War, the non-unions with early compounding of the wound had increased to as high as 95 per cent.

As to infections, the rate increased as the series progressed, for two apparent reasons. In the first place, we were dealing with a much more serious type of case, which had eventually reached the stage in the treatment at which bone-grafting was indicated. Also, the administration of penicillin to great numbers of patients who had never received it before resulted in the prevention of infection in all cases; but as penicillin-treated cases—some with penicillin-resistant organisms—came to bone-graft surgery, the drug was not effective where it was needed most, and the percentage of infections increased rapidly.

INTERNAL FIXATION OF BONE AND NEURORRHAPHY

Combined Lesions of Radial Nerves and Humerus Fractures

BY MAJOR WILLIAM K. MASSIE AND MAJOR ARTHUR ECKER

Medical Corps, Army of the United States

Before the recent advances in chemotherapy, when a wound resulted in a severe lesion of a peripheral nerve, together with a compound fracture, the fracture was treated first and the nerve injury later. Such precedence was required especially in war wounds, because of the considerable risk of infection. Paralyzed muscles were immobilized in plaster for many months, which resulted in incapacitating muscle atrophy and stiff joints. The addition of sulfonamides and penicillin to judicious surgery has permitted more prompt healing of contaminated wounds, and the relatively early use of non-absorbable materials for repair of both bone and nerve. As the risk of infection has diminished, more vigorous measures have been used to maintain and to restore the function of the limb. Galvanic stimulation [11, 12, 19], begun a few days after injury, has minimized atrophy, tended to maintain the blood supply of paralyzed muscles, and prevented adhesions of tendon sheaths and contractures of joint capsules. Furthermore, early surgery on the peripheral nerves has brought regenerating nerve fibers to paralyzed muscles many months, and sometimes years, earlier than was the case formerly, when attention was directed primarily to the healing of the compound fracture.

In the early months of 1945, the authors had under their care, in a General Hospital in England, more than two hundred cases of severe nerve lesions, associated with fractures of the long bones. The majority of the wounds had been caused by shell fragments. These cases were treated according to a program laid down by Spurling. This group included eighty-four cases of humerus fracture, in which exploration of the radial nerve was carried out within a few weeks of injury. In all except two, either neurolysis or satisfactory anastomosis was performed. Of the total group of eighty-four cases, forty-one (48.8 per cent.) required neurolysis only; thirty-five (41.7 per cent.) required nerve suture only; and eight (9.5 per cent.) required internal fixation of bone with shortening, and nerve suture. Each of the eight cases presented a radial-nerve lesion, associated with a compound fracture of the humerus. This report will be confined to an analysis of these eight cases, which had slightly less than a year of follow-up study, and a discussion of the treatment used.

Bone shortening is mentioned in the literature, for the most part, as a means for equalization of limb length [3, 22, 24, 28, 30, 31]. Few actual cases have been reported of shortening of a bone to allow neurorrhaphy, however, although the procedure has been considered for many years [5, 6, 23, 27].

BONE FIXATION AND SHORTENING

It has been shown by Platt that the existence of non-union of fractures, contiguous with sutured nerves, has retarded and prevented recovery, because of tension and friction at the suture sites. In the present series, neurorrhaphy was done at an average of 61.7 days after injury. At this time, the likelihood of non-union could be predicted with fair accuracy. In four of the eight cases, non-union could have been expected, if no operative intervention had been undertaken. In every instance, after each nerve segment had been freed from its bed and resected back to normal-appearing nerve bundles, the hiatus was too great to be overcome by flexion of the distal portion of the extremity without approximation of the nerve ends under considerable tension. Rather than to suture under prohibitive tension, with the knowledge that, as the extremity was subsequently extended, this tension would be increased, skeletal shortening was elected. Danforth's method of radial-nerve trans-

position from the back to the front of the humerus was of no assistance, as the gain in length is present only when the elbow is flexed.

PROCEDURE

Invariably, patients were admitted in shoulder spicas, which usually had been applied at the time of the primary débridement. The wounds were closed by delayed primary suture, and a Kirschner wire was inserted through the olecranon. Until all the sutures could be removed, the limb was placed in overhead traction (Fig. 1) which had the following advantages:

FIG. 1

1. Oedema was diminished markedly, hastening wound healing.

2. Daily electrical stimulation of the muscles of the exposed forearm was possible.

3. Traction force could easily be evaluated to permit alignment, but without distraction of the fragments.

In approximately two weeks, the stitches were removed, and a shoulder spica was applied without discontinuing traction. The Kirschner wire was removed at this time.

In those cases in which a large nerve defect was suspected, comparative roentgenograms were taken of the fractured bone and of its fellow on the normal side. Thus it was learned that, in two of the cases (Cases 1 and 2), shortening of 1 centimeter and of 3.8 centimeters, respectively, had existed prior to operation.

Two weeks after the skin wound had healed com-

FIG. 1

Illustrates type of traction employed immediately after secondary closure, and maintained until wounds had healed. Arm is suspended above chest by wire through olecranon. Weight is adjusted so as to balance arm weight and to cause no distraction of fragments. Pressure dressing and elevation reduce oedema. Forearm is readily available for galvanic stimulation.

FIG. 2

Type of cast employed after discontinuation of traction, but prior to combined operation. A similar cast was applied immediately after operation. Windows are placed in cast to permit stimulation of paralyzed muscles by galvanic current. Finger extension is aided by elastic bands.

FIG. 3-A

FIG. 3-B

Fig. 3-A: Case 3. Patient was injured by shell fragment on October 1, 1944. Secondary closure was carried out twelve days after injury, and combined operation fifty-nine days after injury. Roentgenogram of fracture, October 1, 1944.

Fig. 3-B: Roentgenograms following combined neurorrhaphy and bone shortening; a 2.5 centimeter transverse section of bone was removed on December 1, 1944. The fracture was solid at the time of operation. Note gap between fragments. Absorption at fracture site may increase this gap.

FIG. 3-C

Showing method used.

FIG. 3-D

Bony union complete in five months. Complete regeneration of motor fibers of radial nerve in ten months.

pletely (with loss of the last crust), a nerve exploration was done. Block of the brachial plexus was produced with procaine. A straight, oblique incision, beginning three finger-breadths below the acromion posteriorly and paralleling the lateral border of the long head of the triceps, was extended to the dorsolateral surface of the forearm, following approximately the course of the radial nerve. The cubital-flexion crease was avoided by having the incision pass just anterior to the lateral epicondyle. (Old scars were excised, whenever possible.) The segment of nerve between the teres major and the lateral head of the triceps was exposed by separating the long head from the lateral head of the triceps, and retracting the lateral head of the triceps outward. Additional exposure at the proximal end may be obtained by section of the combined musculotendinous insertions of the teres major and latissimus dorsi with the arm abducted, and then by adducting the arm to the side. The segment of the nerve distal to the penetration of the lateral head of the triceps was exposed anterior to the intermuscular septum. The deep branch of the radial nerve, which penetrates the brachioradialis, was exposed by retracting this muscle group volarward. This exposure, although interrupted by the intact fibers of the lateral head of the triceps above and of the brachioradialis below, seemed superior to the posterior approach described by Henry, because it allowed extension into the forearm and gave adequate exposure to the dorsal antibrachial cutaneous nerve, which was frequently severed.

The nerve was identified above and below the lesion, and was dissected free. The defect of the nerve was not always exactly at the site of the fracture. Occasionally it was found that a missile had passed obliquely through the extremity and had injured the nerve at a point distant from the site of fracture. After the nerve lesion had been disclosed, an estimate was made of the amount of nerve defect to be overcome; the nerve ends were freed from the scar; and the nerve trunk was mobilized as far proximally and distally as would contribute to approximation of the segments. It is noteworthy that adhesions of the nerves to the osteoid tissue at the site of the fracture were especially dense. If it were decided that the bone was to be shortened, the nerve ends were first packed away from the fracture site.

FIG. 4-A

METHODS OF BONE SHORTENING

Under normal conditions, bone grafts would have been substituted for the methods used in at least two of the cases. The methods used were as follows:

A. Transverse Parallel Section

Transverse parallel section of the fragment ends, with the flat surfaces left to be adjusted by coaptation and held by a plate, was carried out in Case 3 (Figs. 3-A, 3-B, 3-C, and 3-D). Although union occurred in this case, there was the risk that absorption at the fracture line might have led to non-union, because the fragments were held apart by a plate.

B. Step Method

In the step method, apposing flanges from each fragment overlap and are held by a plate (Case 4). Although this method provides maximum surface approximation and stability, it requires almost intact fragments upon which to fashion the flanges, and hence is rarely applicable (Fig. 4-C).

FIG. 4-A

Case 5. Patient was injured March 24, 1945. Secondary closure was carried out five days after injury, and combined operation forty days after injury. Roentgenogram of fracture, taken on April 1, 1945.

C. Apposition of Oblique Fragments

Apposing surfaces of oblique fragments are fixed by a plate, and a screw is placed across the fracture at right angles to the plate [20]. This method can be used most frequently (Cases 2, 5, 6, and 7), because the comminuted fragments are usually shaped obliquely. The exact amount of shortening can be altered, even after the surfaces have been ground to fit, merely by sliding the two surfaces over each other (Figs. 5-A, 5-B, 5-C, and 5-D).

D. Semi-Rigid Fixation

This is less desirable than methods of rigid fixation, but in certain conditions it is the only method applicable.

1. The use of one or more screws to hold badly comminuted fragments in place is mentioned only to point out that it is unsatisfactory. It is neither rigid nor elastic, and any strain at the fracture site tends to dislodge the fragments and to promote non-union. This method was not used on any patient in this series.

2. Wire fixation, applied in any pattern which will maintain the fragments in approximately the position attained at operation, was used in Cases 1 and 8. Figures 6-A, 6-B, 7-A, and 7-B illustrate two situations in which plates could not be used. Such massive destruction was present in Case 1 that the main fragments could not be approximated. A large separate fragment was utilized as a bone graft to bridge the defect, but it was too porous to fix with screws. In Case 8 the distal fragment was too close to the joint to permit the use of a plate. However, after wire fixation, the fragments could not be dislodged. The wires were placed to form a figure of eight, anterior and posterior to the fracture; and the two main fragments were prevented from overriding by a single wire loop. This provided

FIG. 4-B

FIG. 4-C

Fig. 4-B: Roentgenograms taken July 25, three months after combined neurorrhaphy and bone shortening of 3 centimeters by the step method. Bony union almost complete. Motor regeneration of radial nerve was 85 per cent. after nine months.
Fig. 4-C: Shows technique used.

FIG. 5-A

FIG. 5-B

Fig. 5-A: Case 2. Patient was injured by mortar, January 26, 1945. Secondary closure was performed ten days after injury, and combined operation sixty-two days after injury. Shows original roentgenogram of the fracture.

Fig. 5-B: Showing details of procedure. Note ability to lengthen or shorten by sliding the fragments.

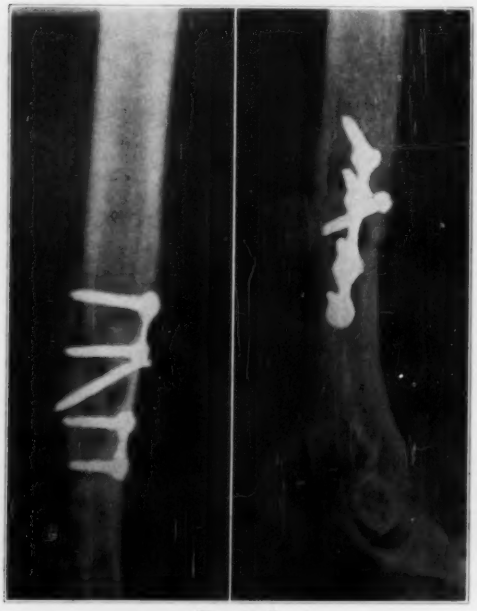

FIG. 5-C

FIG. 5-D

Fig. 5-C: Roentgenograms taken immediately after combined neurorrhaphy and bone shortening of 7 centimeters by the oblique method. Distal oblique fragment was comminuted, but was sufficiently adherent to act as one piece.

Fig. 5-D: Roentgenograms taken January 29, 1946, nine months after operation. Bony union was complete in five months, and motor regeneration of radial nerve was 75 per cent. after ten months.

FIG. 6-A

FIG. 6-B

Fig. 6-A: Case 1. Patient was injured by mortar on January 4, 1945. Secondary closure was carried out on twenty-fifth day after injury. Shows roentgenogram of injury, taken on January 29, 1945.
Fig. 6-B: Roentgenograms taken six weeks after operation (May 4), at which time only slight motion was obtained at fracture site, contrary to the appearance in the roentgenogram. At operation the humerus was shortened 5 centimeters. Note long posterior bone fragment, acting as a bone graft, which was held by wires. (Scarcely visible in reproductions.) Bony union was complete in seven months, although diameter of bone at fracture site was less than normal. Motor regeneration was only 50 per cent. after nine months.

good stabilization anteroposteriorly, but allowed motion in the lateral plane. Alignment could be controlled by plaster fixation.

After fixation of the fragments had been completed, absolute hemostasis was obtained. It was frequently necessary to place mattress sutures into the scar tissue to stop capillary oozing. Fifty thousand units of dried penicillin, diluted with dried plasma, were powdered and shaken into the wound. Neurorrhaphy was carried out according to generally accepted principles of nerve repair [26]. In the case of fractures in the middle third of the humerus, it was usually possible to bring some of the fibers of the lateral head of the triceps between the site of the fracture and the sutured nerve. This was done to minimize the formation of adhesions between the sutured nerve and the fracture site. It also prevented the later development of friction neuritis [9, 21]. However, it did tend to take up some of the slack of the nerve, and emphasized the importance of having shortened the bone.

At the end of the operation, the limb was fixed in a plaster cast which kept the shoulder in forward flexion and abduction, and the elbow in as much flexion as was necessary. A window was cut over the posterolateral aspect of the forearm to permit daily electrical stimulation (Fig. 2).

RESULTS OF BONE FIXATION WITH SHORTENING

As shown in Table I, firm bony union developed in all cases. In Case 1, a supplementary graft [4] might have been advisable to obviate subsequent fracture. In Case 8 a pronounced varus angulation was present, due to improper alignment in the cast (which could have been corrected easily had it been noted when the final postoperative cast was applied).

TABLE I

SUMMARY OF CLINICAL FINDINGS

Case	Time from Injury to Secondary Closure (*Days*)	Time from Secondary Closure to Combined Operation (*Days*)	Time from Injury to Combined Operation (*Days*)	Direction of Missile Through Arm	Area of Bone Comminution (*Cm.*)	Amount of Bone Shortening (*Cm.*)	Nerve Tissue Resected* (*Cm.*)
1 E. G. B.	25	43	68	Posterior to anterior	9.0	5.0	4.0
2 R. A. F.	10	52	62	Posterior to anterior	10.0	7.0	4.5
3 F. W.	12	47	59	No record	1.0	2.5	5.0
4 L. C. S.	13	47	60	Lateral to medial	7.0	4.4	5.2
5 C. E. T.	5	35	40	Anterior to posterior	2.0	3.0	5.0
6 C. L. P.	24	43	67	No record	1.0	3.5	5.0
7 E. H. S.	17	22	39	Anterior to lateral	8.0	4.4	8.0
8 M. N.	18	75	93	No record	5.0	2.5	5.0
Averages	15.5	45.5	61.7		5.4	4.0	5.2

* This is the actual amount of tissue resected, not the length of the gap between nerve ends.

TABLE I (*Continued*)

Time from Operation to Complete Bony Union (X-ray Criterion) (*Months*)	Type of Fixation	Time from Neurorrhaphy to Follow-up Study (*Months*)	Muscles Showing Some Degree of Recovery	Recovery of Voluntary Motion	Amount of Elbow Motion (*Degrees*)
5	Wire	9	Triceps, brachioradialis, extensor carpi radialis longus, extensor carpi radialis brevis	Fair (50%)	70–145
4	Four-hole plate	10	Triceps, brachioradialis, extensor carpi radialis longus, extensor carpi radialis brevis, extensor digitorum communis, abductor pollicis longus	Good (75%)	55–155
8	Four-hole plate	10	Triceps, brachioradialis, extensor carpi radialis longus, extensor carpi radialis brevis, supinator, extensor digitorum communis, extensor carpi ulnaris, abductor pollicis longus, extensor pollicis longus	Normal (100%)	45–150
7	Four-hole plate	6	Triceps, brachioradialis, extensor carpi radialis longus, extensor carpi radialis brevis, supinator, extensor digitorum communis, extensor carpi ulnaris, abductor pollicis longus, extensor pollicis longus	Normal (100%)	40–175
6	Four-hole plate	9	Triceps, brachioradialis, extensor carpi radialis longus, extensor carpi radialis brevis, supinator, extensor digitorum communis, extensor carpi ulnaris	Good (75%)	85–155
8	Four-hole plate	7	Triceps, brachioradialis, supinator	Fair (50%)	No record
5	Four-hole plate	9	Triceps, brachioradialis, extensor carpi radialis longus, extensor carpi radialis brevis, supinator, extensor digitorum communis, extensor carpi ulnaris	Good (75%)	60–165
7	Wire	7	Triceps, brachioradialis, extensor carpi radialis longus, extensor carpi radialis brevis, supinator, extensor digitorum communis	Good (75%)	70–165
6.2		8.4			

This patient was checked by one of the authors, and the angulation does not seem to interfere in any way with function. The permanent effect of the shortening is a little difficult to assess. The flexion contracture of the elbow noted in each case is also quite apparent in humerus fractures of comparable extent, which have been immobilized for prolonged periods [8]. However, this should improve steadily, if the muscle power of the biceps and triceps has not been weakened. All examiners, upon whose opinion we must rely for this follow-up study, agree that muscle power appears normal and that flexion contracture is the result of capsular contracture due to immobilization.

RESULTS OF NEURORRHAPHY

The data for this report were collected on an average of 8.4 months after neurorrhaphy (Table I), so that end results of nerve regeneration could be obtained in only Cases 4 and 5. In Case 4 there was complete recovery in ten months with only mild hypaesthesia; in Case 5, return of both sensation and motor function was considered complete in six months. The brachioradialis was rated as *poor* (25 per cent.). All other muscles were rated as *normal* (100 per cent.). Cases 1, 2, 3, 6, 7, and 8 seemed to be progressing well at the time of reporting, with partial return (Table I). Voluntary muscle return was rated as *normal* (100 per cent.) in one case, *good* (75 per cent.) in three cases, and *fair* (50 per cent.) in the remaining two cases. The progression of the Tinel sign suggested that further improvement could be expected. The value of this test, however, is not beyond question.

DISCUSSION

The authors believe that shortening of the humerus is indicated in certain cases, such as those of this series. It permits neurorrhaphy to be done materially earlier, and the results are not jeopardized by tension and traction of the concomitant unstable fracture.

FIG. 7-A

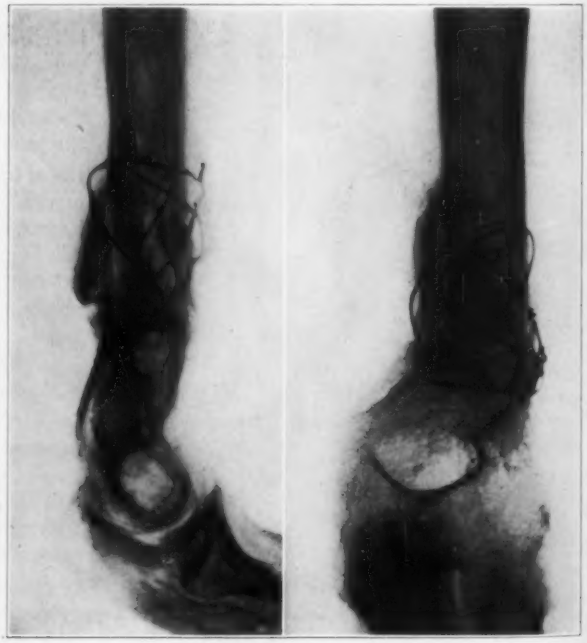

FIG. 7-B

Fig. 7-A: Case 8. Patient was injured March 4, 1945. Secondary closure was carried out eighteen days after injury, and combined operation ninety-three days after injury. Roentgenogram of fracture, taken March 5, 1945.

Fig. 7-B: Roentgenograms taken January 28, 1946. At operation the bone was shortened 2.5 centimeters. The oblique fragments were prevented from telescoping by a single wire loop, penetrating both fragments. Anteroposterior angulation was prevented by a double wire figure of eight. Bony union was complete in three and one-half months. Motor regeneration was 75 per cent. after seven months.

The tension under which suture of the nerve is done can be assessed and determined accurately. The authors feel that it is preferable to shorten the bone more and flex the elbow less, in order to obviate the postoperative stretch on the nerve required to extend the elbow. Highet and Holmes suggested nerve graft in this dilemma, but the grafting of large nerve trunks has not proved feasible clinically, although experimental work on animals is encouraging [29].

In a follow-up study of nerves which at operation had been sutured under tension or in a position which would subsequently exert tension, Highet and Sanders showed conclusively the dire results of tension. Of six cases of popliteal suture after extensive resection, one showed regeneration, and this was the only case in the series in which only six centimeters had been resected. Re-exploration in three cases showed intraneural hemorrhage with fibrosis, extending both proximally and distally to the suture line to such an extent as to prohibit resection and suture. The amount resected in each of the instances in which recovery failed did not exceed the more conservative estimate made by both Forrester-Brown and Babcock as being compatible with the return of function for this nerve. Highet also reported seven cases of radial-nerve resection of amounts not exceeding six centimeters, and all patients showed some degree of recovery. The average amount resected in this series was 5.2 centimeters, but this does not include the length of nerve destroyed completely at the time of injury. The length of nerve excised is rather confusing. Table I presents actual measurements of the amount of tissue removed from both segments before healthy fasciculi were reached. It does not include the amount of nerve tissue which was inextricably bound up with the osteoid tissue of the fracture, nor does it indicate the gap between the segments after such excision. Therefore, we have no accurate measurement of the total length of nerve destroyed, nor could we determine any method by which this could be measured accurately. The nerve retracts after being severed; and, when continuity has been restored, the more traction that is applied, the less seems to be the original defect. In all of these cases, an attempt was made to restore normal tension with only moderate flexion of the distal portion of the extremity, and to make up the deficit by bone shortening.

A report by Hoen suggests that the danger in postoperative stretching of a sutured nerve affects particularly the distal fragment. His recent work (reported to the Harvey Cushing Society in October 1946) suggests that good results are obtained when traction has been applied to the proximal fragment only. If this method of dealing with wide gaps proves successful, it will lessen still further the proportion requiring skeletal shortening.

The time saved by the combined procedure in restoring the arm to normal function can be estimated in terms of months. The percentage of normal function which is recovered varies directly with the length of time after injury at which nerve regeneration is attained. As regeneration is delayed, the number and severity of irreversible changes in the nerve and in its end plates increase. The size of the nerve trunk itself is diminished, as shown by Young; but more severe are the changes in the numerous end plates which, although they may function again, are greatly reduced in efficiency [13]. Secondarily, muscle fibrils seriously affected by delayed innervation are gradually encroached upon by interstitial fibrosis and, when re-innervation is postponed for a year or more, cellular changes in the muscles denote the beginning of a degenerating process which progresses steadily to complete disintegration in approximately three years [2]. How long this destruction can be postponed by regular periods of galvanic stimulation is debatable [12]. More definite are the grave effects of prolonged immobilization [18], which is inevitable when injuries of bone and nerve are treated successively rather than concurrently.

Only one patient in this series received a skin graft to effect secondary closure. If oedema was carefully prevented, wounds could be closed under tension not previously thought advisable; but where gross skin loss was present, skin-grafting had to be carried out. The delay which this entailed, however, prolonged the time from injury to healing an

average of at least three weeks, and made it impracticable to treat these patients in the Zone of Communications.

In Table I is recorded the area of the comminution in centimeters. When compared with the actual amount of bone shortening attained, it is obvious that in most cases the shortening was accomplished without the ablation of any uninjured bone.

Correlation of the amount of bone damage to the amount of nerve resected depends upon such variables as the immediate care after injury, and the direction and speed of the missile. Only very broad and indefinite conclusions can, therefore, be drawn. It was noticed repeatedly, and is borne out by perusal of Table I, that missiles which entered from such a direction as to hit the bone before they reached the nerve caused more extensive damage, and that the damage was inversely proportionate to the speed of the missile.

Penicillin was used before and after operation in each case. The authors are convinced that the absence of any infection, following a major procedure performed on an extremity in which open granulation had so recently been present, was due to the use of this substance.

SUMMARY AND CONCLUSIONS

1. Eight cases of compound fracture of the humerus with radial-nerve laceration were treated by neurorrhaphy and bone shortening within an average of sixty days of the injury.

2. Bony union was complete in all cases.

3. Nerve regeneration was progressing satisfactorily in all cases, but was complete in only two at the time the patients were last seen. The importance of early and adequate galvanic stimulation of paralyzed muscles is stressed.

4. No ill effects are demonstrable from shortening of the humerus up to one-fifth of its length.

5. Early nerve suture is of paramount importance.

6. When suture necessitates prohibitive tension on the nerve, either at operation or during postoperative stretching, concomitant bone shortening in the arm is feasible. At present, this is considered preferable to tendon transplantation in the forearm at a later date.

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THE RELATION OF DISCOID MENISCUS TO CYST FORMATION AND JOINT MECHANICS

BY J. KULOWSKI, M.D., ST. JOSEPH, MISSOURI, AND
H. W. RICKETT, M.D., TACOMA, WASHINGTON

The following case of discoid meniscus is reported because it brings up the still debatable question of the origin of cyst of the meniscus, and also because it apparently demonstrates a fundamental principle of the mechanics of the knee joint.

J. B., a white woman, aged twenty-one years, had complained of pain, tenderness, and swelling of the right knee of four months' duration; this was noted especially after active sports. A palpable swelling and significant widening of the lateral portion of the joint space suggested a cyst of the lateral meniscus. At operation, a small cystic mass and a completely discoid cartilage were encountered (Figs. 1-A and 1-B); the upper surface of the cartilage presented a remarkably eroded area.

These findings recalled the discussion in regard to the origin of meniscus cyst, and the automatic coaxial movements of the knee which must have caused the defect on the cartilage surface.

Of the current theories relating to the formation of cysts of the lateral meniscus, Ollerenshaw holds to their congenital origin. Other writers do not [8], mainly because of the paucity of cysts associated with malformation, and their denial [3] of the existence of an endothelial lining in cysts, spoken of by C. E. Jenkins, the pathologist who examined the specimens taken from all of Ollerenshaw's cases. Jenkins [7] stated that: "No reliance can be placed upon silver as a means of demonstrating cells". He illustrates this point by two photomicrographs in which a silver-stained section was counterstained with hematoxylin; the second staining brought out an increased number of cells, forming a sort of lining membrane in a cyst of the lateral meniscus.

The recorded instances of cysts associated with malformation do lend some support

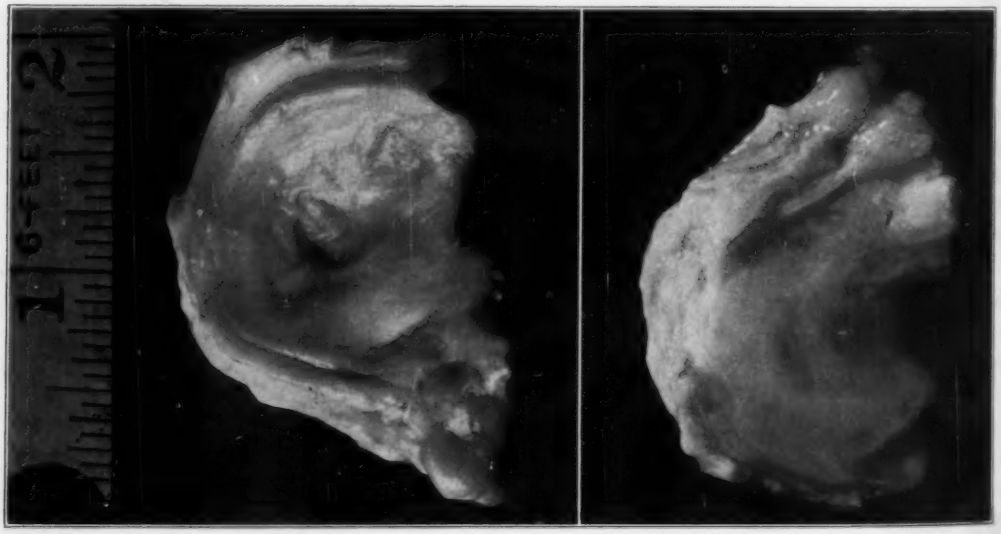

FIG. 1-A

FIG. 1-B

Fig. 1-A: The femoral surface of the discoid cartilage is shown. The lower margin in the photograph is the anterior limit. The eccentric area of attrition and the complete attachment to the synovial membrane are notable.

Fig. 1-B: The tibial surface of the cartilage is intact. The anterior limit is in the upper part of the photograph.

to Ollerenshaw's concept. Herzmark reported a case of bilateral "giant" external menisci, and mentioned mucoid degeneration in one of them. Meekison recorded one case, and Ober two instances, of cyst formation in malformed lateral menisci. Ollerenshaw, in recording the only instance which he observed of cyst arising from the medial or free border of a lateral meniscus, described the cartilage as being broad in structure (Fig. 2). He pointed out that the lateral meniscus is by far the most frequent site of cyst formation (as observed in thirty-six of his own forty-two cases), although it is less apt to become injured. Of the fifty or more malformed menisci which had been reported up to 1941, only two involved the medial meniscus.

One of the authors (J. K.), in reporting nineteen cases of cyst of the lateral meniscus,

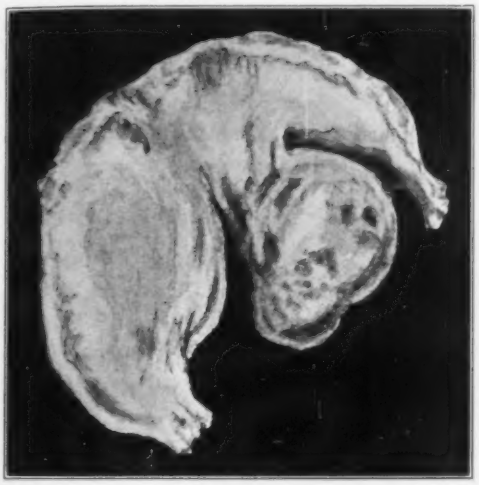

FIG. 2

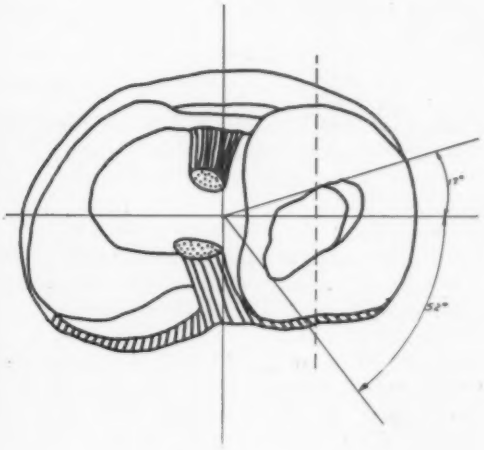

FIG. 3

Fig. 2: Malformed lateral meniscus with cyst formation at its medial or free border (redrawn from Ollerenshaw). (Reproduced, by permission, from *The British Journal of Surgery*, **23**: 278, 1935.)

Fig. 3: Drawing represents the upper surface of the tibia and discoid cartilage in the present case. The area of attrition subtended an angle of about 70 degrees, and was presumed to have been caused by coaxial movements between the fixed lateral cartilage and the femoral condyle,—the anterior half by the pinching stresses in the position of extension, and the posterior half by the rotational component of movement.

noted that three were associated with variable degrees of malformation, with no evidence of trauma. In one, a boy of fifteen years, there was an enlarged but annular type of cartilage. In another (a case of Steindler's which was included in that series), both lateral menisci were discoid, with cystic changes in one of them. In the third, a male of thirty-three years, there was a comma-shaped malformation in the anterior half, with cystic changes therein. In the case reported here, unfortunately, the microscopic examination was confined to the eroded area alone, and no cystic changes were described there. It may be that the cyst found at operation was wholly parameniscal. However, it would seem justifiable to conclude that at least some cysts are congenital in origin, in so far as compression of a malformed cartilage would accelerate a secretory response in cells which had retained some of their embryonal character.

Ordinarily the clinical symptoms of an uncomplicated malformed (biconcave) lateral meniscus are due to malalignment of the joint surfaces by this interposed structure. When this cartilage is attached loosely, it slips and causes reposition of the condyles. This is accompanied by an audible and palpable snap or thud ("trigger" knee). What happens when the cartilage is firmly attached was illustrated in the present case. Since it was practically fixed to the tibia, the grinding and twisting action of the joint impressed itself upon the fixed interposed discoid cartilage during the automatic coaxial excursions which are known to occur in the knee (Fig. 3).

According to Steindler, the movement of flexion is essentially a pure rocking motion during the first 20 degrees, after which it becomes a gliding action of the tibia on the femur. During the latter excursion, 50 or 60 degrees of rotation occur. Flexion is started with an inward rotation of the tibia against the femur, and extension is completed by a reverse rotation. The ability to rotate the leg inward makes it possible for the leg to bring the foot forward in walking. As the swinging leg is set to the ground, the forward rotation of the pelvis results in an outward rotation of the limb. Then, as the foot deploys while the other free-swinging side of the pelvis comes forward, the standing knee goes into flexion and, with it, inward rotation of the tibia begins on the standing side. Since the longitudinal axis falls within the medial condyles, the lateral tibial condyle makes the greater excursions. Thus was the peculiarly directed erosion of the femoral surface of the cartilage, reported here, a prerequisite for the fulfillment of the coaxial movements of the affected joint.

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THE TRANSFER OF WRIST EXTENSOR MUSCLES TO RESTORE OR REINFORCE FLEXION POWER OF THE FINGERS AND OPPOSITION OF THE THUMB *

BY GEORGE S. PHALEN, M.D., CLEVELAND, OHIO, AND
RICHARD C. MILLER, M.D., KANSAS CITY, MISSOURI

When a surgeon is called upon to restore active motion to a paralyzed hand, he must take great care in determining the type of operative procedure which will produce the best result. Each case is an individual problem. The surgeon must examine the hand carefully to ascertain, first of all, what necessary motor functions are lacking; and then he must decide what active muscles are available for transfer into the paralyzed muscles.

The flexor carpi radialis, the flexor carpi ulnaris, and the palmaris longus muscles are frequently employed to restore or reinforce flexion power of the fingers and opposition of the thumb. The wrist and finger extensor tendons have been employed much less commonly for this purpose.

On the Hand Service of an Army General Hospital, the authors encountered patients with loss or diminution of flexion power in the wrist and fingers secondary to injury of the brachial plexus, combined injury of the median and ulnar nerves, or actual destruction of the substance of the flexor muscles. The restoration of flexion power to these crippled hands presented a difficult problem.

Probably the two most common methods of treating such cases are arthrodesis of the wrist with transfer of the three wrist extensors, or tenodesis of the flexor tendons to obtain automatic flexion of the fingers when the wrist is extended. The authors believed that the mobility of the wrist joint might be retained and the flexor power of the fingers restored by a transfer of one of the radial extensor muscles of the wrist into the flexor tendons of the fingers.

In an occasional case of incomplete palsy of the median and ulnar nerves, the wrist flexors were found to be strong and the finger flexors were weak. In these cases, when it became obvious that there would be no further return of nerve function, we had been using the flexor carpi radialis to reinforce the finger flexors; but, after observing some of the end results of wrist extensor transfers in cases in which no wrist flexors were available, we concluded that the extensor carpi radialis longus or the extensor carpi radialis brevis was a better muscle to reinforce the finger flexors than the flexor carpi radialis. Extension of the wrist and flexion of the fingers are more of an associated movement than flexion of the wrist and flexion of the fingers. It was apparent in these cases that much more power of flexion was imparted to the fingers by transfer of the extensor carpi radialis than by transfer of the flexor carpi radialis.

The authors have performed this type of tendon transfer in eight cases,—four cases of injury of the median and ulnar nerves or brachial-plexus palsy, involving primarily the median and ulnar nerves, and four cases of irreparable muscle damage, involving the flexor muscles in the forearm.

In the latter group—those with muscle damage—one patient with only a few degrees of flexion power in the index finger and none in the remaining fingers, but with a normally supple and mobile hand, obtained an excellent result, with ability to make a strong fist. The long flexor muscle of the thumb had not been damaged seriously.

Two patients with much less supple and mobile hands obtained considerable improvement. When last seen (approximately three months after operation) they still could not

* Read at the Annual Meeting of the American Society for Surgery of the Hand, Chicago, Illinois, January 25, 1947.

FIG. 1-A FIG. 1-B

The extensor carpi radialis longus has been transferred into the flexor digitorum profundus tendons to restore flexion power to the fingers. There had been extensive loss of muscle substance in the forearm. Photographs show fingers extended (Fig. 1-A) and flexed (Fig. 1-B), approximately two months after the tendon transfer.

bring the finger tips to within more than an inch of the palm, but each patient had a fairly strong grip for large objects.

One of these two patients was an Army sergeant, who sustained a severely lacerated wound, involving the left forearm, with considerable loss of flexor-muscle substance. A large abdominal pedicle graft was applied to the volar surface of the forearm. The median and ulnar nerves in the forearm were incompletely damaged. There was a fairly good sensation over the palm and the volar aspect of the fingers; and the intrinsic musculature of the palm was partially functioning. There was a severe adduction contracture of the thumb, and there was no power of flexion in the fingers or thumb. A Z skin plasty and a stripping of the adductor pollicis muscle from the thumb were done to relieve the contracture of this digit, and the extensor carpi radialis longus tendon was transferred into the flexor profundus tendons of the fingers. Figure 1-B shows the result of this tendon transfer, approximately two months after operation. The flexor pollicis longus was motivated by the brachioradialis at a subsequent operation.

Another patient in this group had a very badly scarred hand, with marked adhesions along the course of all flexor tendons in the palm and fingers; and the transfer was done after a tendolysis of the flexor tendons. There was very little improvement in this case, although the patient was last seen only five weeks after operation. The authors felt that all of these patients would continue to improve with further active use of their hands.

In the group of cases with nerve injuries, three patients achieved a strong grip with fingers touching the palm, and the fourth patient obtained flexion of his fingers to within one and one-half inches of the palm. As one would expect, the end results in this group were better, as far as flexion was concerned, than in the group with muscle damage, because

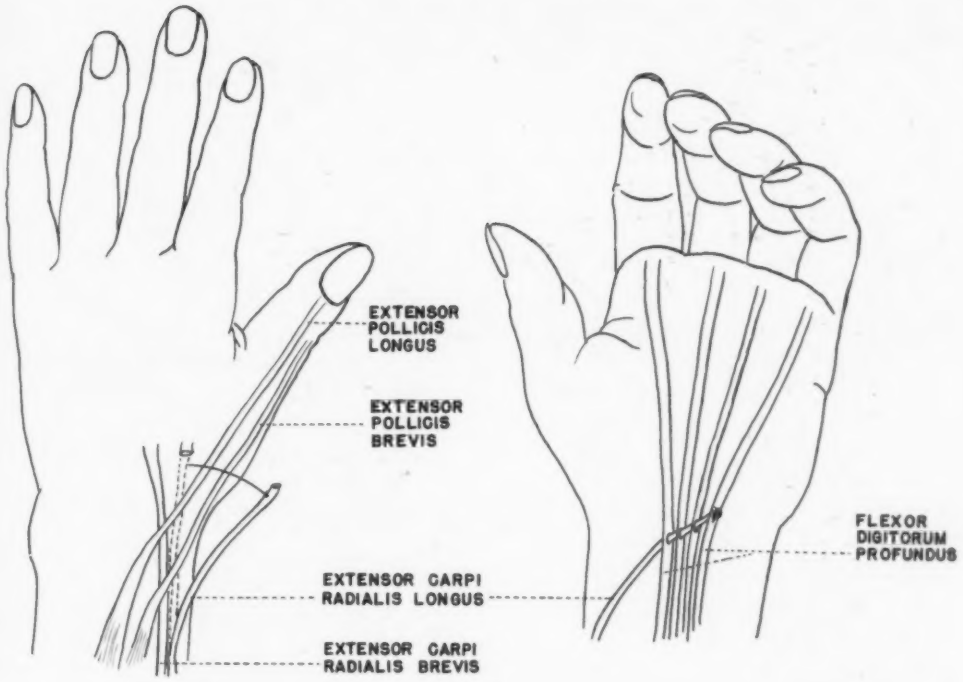

FIG. 2

Diagram showing transfer of extensor carpi radialis longus tendon into flexor digitorum profundus tendons. The extensor tendon is severed close to its insertion, as shown at the left, and is then freed well up into the forearm, rerouted subcutaneously onto the volar aspect of the wrist (as shown at right), and inserted into the flexor profundus.

of the absence of joint limitation and scarring, so frequently associated with the muscle injury. However, two patients had imbalance from intrinsic-muscle paralysis, and extension of the distal joints of the fingers was unsatisfactory.

In these transfers, the extensor carpi radialis longus was used most frequently, although in one case the extensor carpi radialis brevis was employed. The tendon was severed at its insertion, freed well up into the forearm, and then rerouted subcutaneously to the volar surface of the wrist and inserted through buttonholes in the flexor profundus group (Fig. 2). In one case, the extensor carpi radialis brevis was inserted into the flexor sublimus group, and the end result was very satisfactory. In some cases, the transferred tendon was passed beneath, instead of superficial to, the flexor carpi radialis tendon. Little difference was observed between these two methods of transfer. It was felt, however, that it was important to make the transferred tendon pull in as direct a line as possible.

The authors have also employed the extensor carpi ulnaris tendon as the motor element of a tendon transfer to restore opposition to the thumb in seven cases in which no flexor tendons were available for the transfer. In all of these cases, some power was present in the flexor muscles of the fingers; but these muscles were so weak that the authors did not feel justified in weakening further the flexion power of a finger by sacrificing a sublimus tendon for the transfer. No wrist flexor tendons were available for transfer in any of the cases.

The extensor carpi ulnaris did not make so effective an opponens transfer as a flexor muscle would have done, but the end results in these badly crippled hands were quite satisfactory. A thumb, lying useless by the side of the hand, was given the ability to rotate across the palm and to oppose the index finger, middle finger, and ring finger; and, in at least half the cases, the thumb could also touch the tip of the little finger.

In all of the cases in this series, the tendon of the extensor pollicis brevis was severed at its musculotendinous juncture, transferred subcutaneously across the thenar eminence, and sutured to the cut end of the extensor carpi ulnaris, which had previously been severed

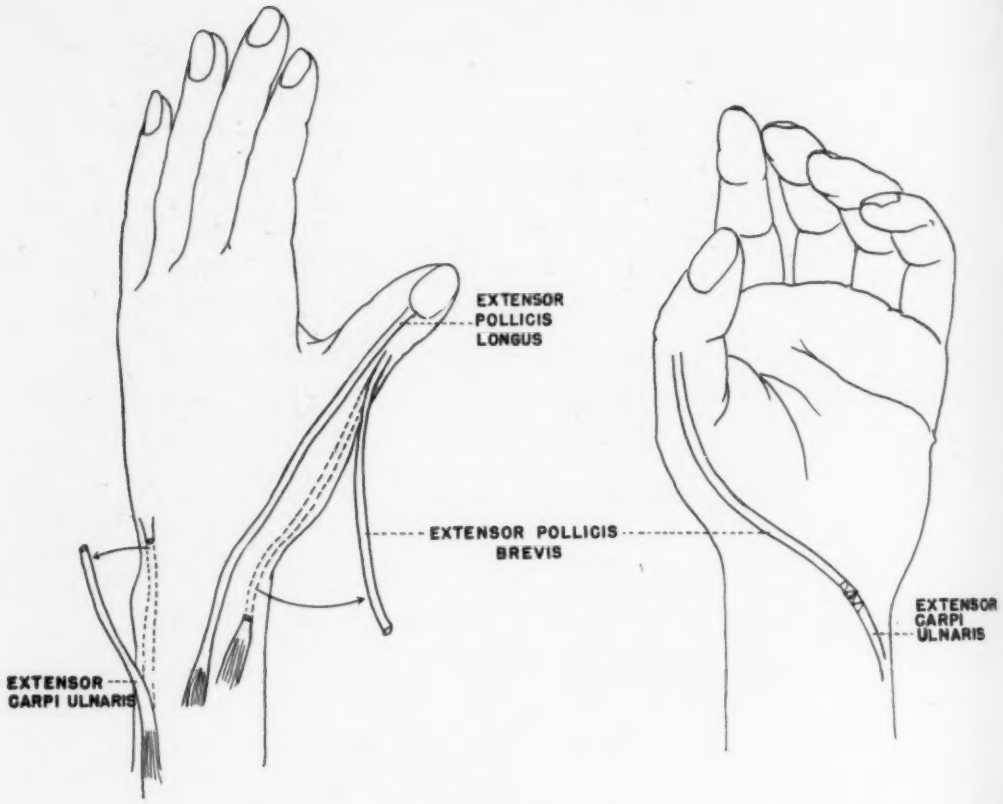

FIG. 3

Diagram showing transfer of extensor carpi ulnaris tendon to serve as the motor element of a tendon transfer to restore opposition to the thumb. In the drawing at the left, the extensor carpi ulnaris tendon has been severed at its insertion, and the extensor pollicis brevis has been cut at its musculotendinous juncture and withdrawn at its insertion into the base of the thumb. In the drawing at the right, the extensor pollicis brevis tendon has been rerouted subcutaneously across the palm, and sutured to the extensor carpi ulnaris tendon at the medial side of the volar aspect of the wrist. A free tendon graft may be substituted for the extensor pollicis brevis tendon, if the latter is not available.

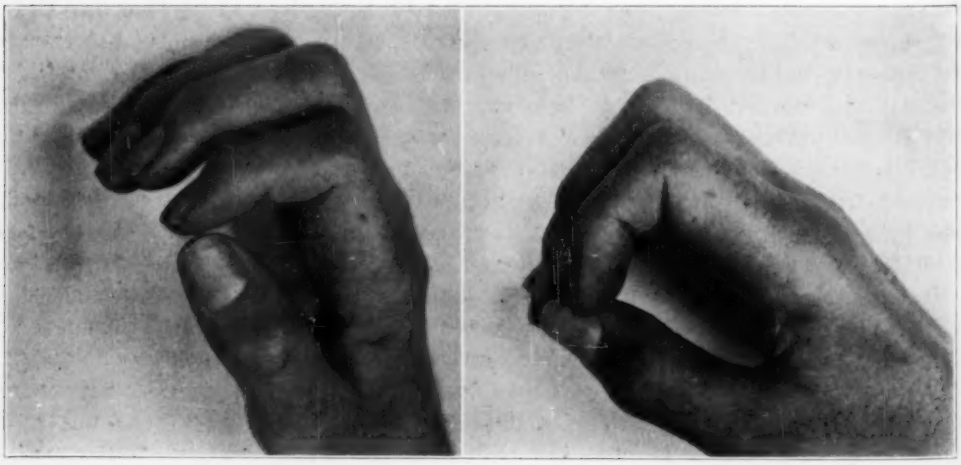

FIG. 4-A FIG. 4-B

Fig. 4-A: Photograph of the right hand of a patient with paralysis of the median and ulnar nerves, showing inability to oppose the thumb to any of the fingers.

Fig. 4-B: Shows the same patient, four weeks after the thumb had been motivated by transfer of the extensor carpi ulnaris tendon.

FIG. 5-A FIG. 5-B

Showing the left hand of a patient with a brachial-plexus injury, involving primarily the median and ulnar nerves. Fig. 5-A shows extension and Fig. 5-B shows opposition of the thumb, two months after transfer of the extensor carpi ulnaris tendon. Function in this hand was greatly improved by the transfer. Prior to operation, the thumb could neither be adducted across the palm nor opposed to any of the fingers.

at its insertion and transferred subcutaneously to the medial side of the volar aspect of the wrist (Fig 3). No attempt was made to create a pulley at the pisiform bone, as is usually done when a flexor muscle is used as the motor power in such a transfer. Care was taken to keep the extensor carpi ulnaris tendon in the subcutaneous tissue, in order to avoid any adherence of the tendon to the underlying ulna.

One of these patients was an Army sergeant who sustained multiple saber cuts on his right forearm, involving the median and ulnar nerves. The nerves were sutured, but there was no evidence of any return of function in the intrinsic muscles of the hand after eight months. There was profound disability in the hand; the patient was unable to touch the tip of his thumb to the tip of any finger (Fig. 4-A). Because of the weakness of the finger flexors, it was thought not advisable to sacrifice one of the sublimus tendons to act as the motor power in the transfer of the thumb opponens; therefore the extensor carpi ulnaris tendon was used instead. Four weeks after the transfer of the extensor carpi ulnaris, the patient was able to oppose the thumb to the index finger, middle finger, and ring finger; after another month, he was able to oppose the thumb to all of his fingers.

A similar case is illustrated by Figures 5-A and 5-B. This Army private sustained a brachial-plexus injury, with involvement primarily of the median and ulnar nerves. The thumb remained useless at the side of the palm; it could neither be adducted across the palm nor opposed to the tip of any of the fingers. The flexor carpi radialis and the flexor carpi ulnaris were not functioning, and there was no palmaris longus tendon. There was some power of flexion in all of the fingers and the thumb, but this power was not sufficient to warrant sacrificing one of the flexor sublimus tendons to serve as the motor power for an opponens transfer to the thumb. Consequently, the extensor carpi ulnaris was employed; and the end result was very satisfactory. The patient was able to oppose his thumb to all of his fingers.

TRANSPOSITION OF FINGERS IN SEVERE INJURIES OF THE HAND

BY LIEUTENANT COLONEL WALTER C. GRAHAM*, COLONEL J. BARRETT BROWN*, LIEUTENANT COLONEL BRADFORD CANNON*, AND CAPTAIN DANIEL C. RIORDAN

Medical Corps, Army of the United States

From the Hand Service of the Valley Forge General Hospital, Phoenixville, Pennsylvania

Penetrating wounds of the hand, caused by shell fragments or bullets which enter either the palm or the dorsum of the hand and pass completely through, result in severe damage to bones and soft tissues. Wounds of this nature usually occur in combat areas and, therefore, complete débridement with primary closure cannot be done. Occasionally, secondary closures are carried out. Due to the type of the injury, extensive scarring always occurs along the course of the missile, extending completely through the hand. This scar involves the tendons, nerves, and intrinsic muscles, and is nearly always adherent to the bone. The loss of tendon and nerve function of the finger results in a so-called "dead finger". In some cases the blood supply to the finger is jeopardized, which results in a swollen, cyanotic finger. When an amputation has been performed previously, the flexor tendons are frequently found adherent to the scar, preventing flexion of the remaining fingers. When the finger has not been amputated, the flexor tendons are caught in the scar and will gradually pull the involved finger into a flexed position, thus preventing function of the finger, and inhibiting the function of the remaining fingers. Frequently there is a painful neuroma in the scar which prevents the patient from using the hand, since any light touch causes extreme discomfort.

FIG. 1-A

In the reconstruction of the severely damaged hand, the first consideration is complete excision of scar tissue, which leaves a large soft-tissue defect of the hand. The closure of such a defect would require a pedicle flap. The two objectives which guide this reconstruction are to restore the most function and to attain the best appearing hand. In those cases in which the long or the ring finger has been amputated, or in a so-called "dead finger", we have found it advisable to transpose the adjacent finger, together with its metacarpal, thus eliminating the defect and approximating normal, healthy tissue. By transposing the normal metacarpal and finger into the defect which has resulted from the amputation and resection of the scar, the hand is narrowed, but the appearance and function are improved. This places the remaining fingers parallel and prevents the deviation and rotation of the adjacent fingers into the defect, as happens when a finger and a portion of the metacarpal are amputated. When the damage involves the bony structures and tendons to the ring or long fingers, we resect the scar tissue and severely damaged metacarpal down to the base. If the defect involves the ring finger, osteotomy is performed on the fifth metacarpal near its base, and the fifth metacarpal is transposed to the base of the fourth metacarpal. If the long finger is involved, osteotomy is performed on the second metacarpal which is then transposed to the base of the third.

Occasionally it is advisable to transpose the index finger to the first metacarpal to

*See note, page 1004.

replace the amputated thumb. How crippling is the loss of the thumb to the function of the hand is well known; to replace it with a digit which has sensation and muscle control is an extremely valuable procedure. In transferring the index finger to the thumb, many points must be considered. Probably the first in importance is the length of the digit. If it is to function as a thumb, it should be shortened from one to two inches, so that in the opposed position, with the fingers partially flexed, it will not extend beyond the ends of the fingers. Also, the finger must be rotated almost 90 degrees and must have sufficient cleft to allow the opposed position and abduction.

If the index finger is to function as a thumb, the nerve and blood supply must be

FIG. 1-B

FIG. 1-C

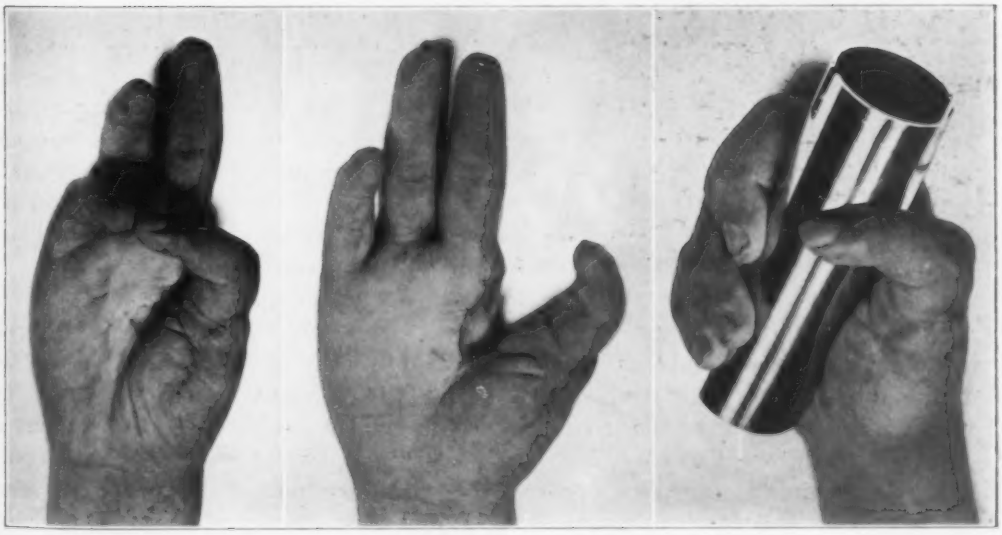

FIG. 1-D FIG. 1-E FIG. 1-F

CASE 1. Patient was struck on right hand with shell fragments, losing the thumb at the metacarpophalangeal joint. There was severe comminution with loss of bone substance of the second metacarpal. Treatment included transplanting the index finger to replace the missing thumb, fixing the finger to the first metacarpal, and filling in defect with a local flap and split-thickness skin graft.

Figs. 1-A and 1-B: Photograph and roentgenogram of the hand upon admission.

Fig. 1-C: Roentgenograms of hand after transposition of index finger.

Figs. 1-D, 1-E, and 1-F: Final appearance of the hand after rehabilitation.

FIG. 2-A FIG. 2-B

CASE 2. Patient was injured by bullet passing through the right hand; bullet entered the palm with exit on the dorsum of the hand, causing tremendous scarring. The middle finger was amputated and the index finger was transposed to the position of the middle finger.

Fig. 2-A: Original palmar view.

Fig. 2-B: Dorsal view upon admission.

Fig. 2-C: Postoperative roentgenograms.

Fig. 2-D: Final palmar view.

Fig. 2-E: Final dorsal view.

FIG. 2-C

FIG. 2-D

FIG. 2-E

carried with it. This necessitates splitting the digital nerve slip of the adjacent sides of the index and middle fingers well up into the base of the hand, as well as freeing and dividing the vessels necessary to allow the transposition. The tendon control of the index finger is preserved and maintained to control flexion and extension of the newly formed thumb. This results in a thumb which will oppose the fingers, have normal sensation, and have flexion and extension control, as well as the ability to grasp large or small articles.

Dial reported a case in which he lengthened the thumb with a tube graft, stabilizing it with a bone graft. Albee applied a tube and a bone graft to the hand stump, so that the remaining thumb would oppose a stable stub finger. Reports have appeared in the Italian literature on phalangization of the first metacarpal. In the above cases, the first metacarpal was kept in its position and the cleft between the first and second metacarpals was deepened. Nuzzi presented examples of this type of procedure and stated it had been

used by Cipollino and Guermonprez-Klapp and others. Rinaldo's procedure was of a similar nature.

The conversion of another digit to act as a thumb is an operation which has been performed many times. Joyce reported two cases in which the ring finger from the opposite hand was transposed to act as a thumb. In these cases, no attempt was made to suture the nerve, but Joyce stated that there was a return of some sensation. He reported no motion in the two distal joints. Dunlop suggested a method similar to the one here described, but he had not performed

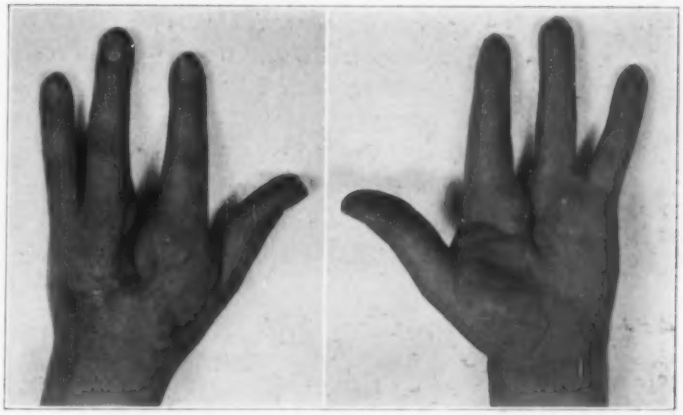

FIG. 3-A FIG. 3-B

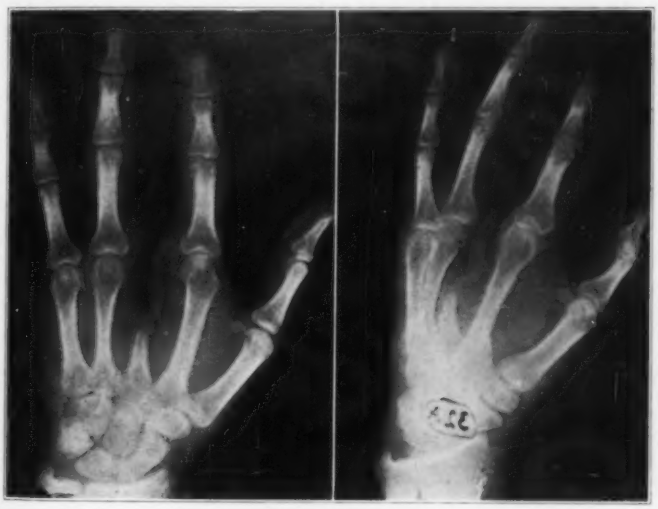

FIG. 3-C FIG. 3-D

CASE 3. Patient was injured when a rifle bullet passed through his left hand, tearing out the middle finger, and leaving a large cleft in the hand. He was treated by the transposition of the ring finger to fill in the defect caused by the loss of the middle finger.

Fig. 3-A: Original dorsal view of the hand.

Fig. 3-B: Volar view.

Fig. 3-C: Roentgenograms upon admission.

Fig. 3-D: Postoperative roentgenogram.

Fig. 3-E: Final palmar view.

Fig. 3-F: Dorsal view.

[Figs. 3-A, 3-B, and 3-D reproduced by permission of The Yorke Publishing Co., Inc., (Snedecor, S. T.: Bone Surgery of the Hand. *The American Journal of Surgery*, Vol. 72, p. 370, Sept. 1946).]

FIG. 3-E FIG. 3-F

FIG. 4-A

FIG. 4-B

FIG. 4-C

FIG. 4-D

CASE 4. Shell-fragment wound of the hand, with loss of ring finger and complete destruction of the metacarpophalangeal joint of the middle finger. Patient was treated by local flap to the dorsum of the hand, arthroplasty to the metacarpophalangeal joint of the middle finger, excision of the fourth metacarpal, and transposition of the middle finger to the position of the ring finger.

Fig. 4-A: Original roentgenograms of the hand.

Fig. 4-B: Final roentgenograms.

Figs. 4-C and 4-D: Final views of the hand.

[Figs. 4-A and 4-B reproduced by permission of The Yorke Publishing Co., Inc. (Snedecor, S. T.: Bone Surgery of the Hand. *The American Journal of Surgery*, Vol. 72, p. 369, Sept. 1946).]

the operation. Tonnini converted the index finger to act as the thumb. The method which he used was somewhat similar to that here described; he attached the tendons of the lost thumb for the motor power, but did not shorten the converted digit. We felt that this was undesirable and we retained the motor power of the converted finger.

TRANSPOSITION OF INDEX FINGER TO REPLACE THUMB

The operative technique for the conversion of the index finger to the thumb was carried out in two stages. As seen by the roentgenograms, the thumb was missing near the metacarpophalangeal joint. It so happened that there was also considerable loss of bone substance and scarring along the second metacarpal.

In the first stage of the operation, a dorsal approach was made, and the scar tissue was removed. The distal portion of the second metacarpal was excised, as well as the articular surface and one-half inch of the proximal phalanx of the index finger. The transverse metacarpal ligament was sectioned, and the index finger was freed so that it would retract almost two inches, care being taken to preserve the arteries and the nerves. The first metacarpal was shortened about one-half to three-quarters of an inch, and, by rotating and retracting the index finger, we were able to bring the first metacarpal and the proximal portion of the proximal phalanx of the index finger in contact. They were fixed in this position with stainless-steel wire. At this point, attention was directed to securing the proper rotation of the index finger to give opposition. The wound was then closed, and a period of six weeks intervened before further surgery was carried out.

FIG. 5-A

FIG. 5-B

FIG. 5-C

CASE 5. Rifle bullet through the palm of the hand caused great loss of soft tissue and bone substance of the ring finger. Treatment included excision of scar, amputation of the ring finger, and the transplanting of the little finger to the stump of the fourth metacarpal.

Fig. 5-A: View of the hand before surgery.
Fig. 5-B: Original roentgenogram of hand.
Fig. 5-C: Final roentgenogram of hand.
Fig. 5-D: Final view of the hand.

[Figs. 5-A, 5-B, and 5-C reproduced by permission of The Yorke Publishing Co., Inc. (Snedecor, S. T.: Bone Surgery of the Hand. *The American Journal of Surgery*, Vol. 72, p. 369, Sept. 1946).]

FIG. 5-D

At the second stage, the division was made between the index and middle fingers; the incision extended from the base of the palm to the base of the metacarpals dorsally. A dorsal flap was raised to fill the base of the cleft. The vessels anastomosing between the middle and index fingers were freed, leaving the arteries and blood supply to the index finger. The cutaneous nerve branches to the index finger were freed well into the base of the hand. The proximal pulley for the flexor tendon of the index finger was completely excised to free the tendons. Dorsally, the extensor tendons to the index finger were rerouted to the radial side of the wrist so that their direction of pull would simulate that of the extensors of the thumb. The remaining exposed surface was then covered with a split-thickness skin graft, taken from the thigh. In the process of dividing the index and middle fingers, the intrinsic muscles were left with the middle finger, so that they would act in a normal manner. The abductors and adductors of the thumb were attached to the converted index finger and thus had their normal function and action. This new thumb was held in a position of abduction and opposition for a period of three weeks, followed by a period of occupation and rehabilitation.

TRANSPOSITION TO REPLACE CENTRAL FINGER

To a great extent the line of incision must be controlled by the scar tissue which is present on the dorsal and palmar surfaces of the hand. It is frequently necessary to curve the incision in order not to jeopardize the remaining soft tissue. In the palm of the hand, it is very important to avoid straight incisions, as they tend to cause contracting scars.

If the so-called "dead finger" still remains, it is amputated down to the base of the metacarpal, leaving about three-eighths of an inch of the base. All adherent tendons, neuromata, and damaged muscle tissue are excised completely. Osteotomy of the metacarpal of the finger which is being transposed is then performed at the same level, and the metacarpal is moved centrally over the base of the amputated metacarpal with its intrinsic muscle still attached. The transposed metacarpal is held in its new position by

two Kirschner wires, put through obliquely into the adjacent metacarpals. When the wires are inserted, great care is taken to have the rotation of the metacarpal exactly correct, thus allowing the metacarpophalangeal joint to move in the proper plane. The metacarpal ligament is also repaired.

The hand is put in a firm pressure dressing and supported for a period of three weeks. At the end of that period, active motion, which includes physiotherapy and occupational therapy, is instituted. At the end of six or seven weeks, the Kirschner wires are removed.

The procedure of collapsing the hand narrows it moderately, but not enough to weaken the hand to any extent. Any weakness which may result from narrowing the hand is far overshadowed by the advantages gained in having the fingers approximated so that they will function as a unit. Further surgical procedures may be indicated, at some later date, to restore complete balance and function to the hand.

SUMMARY

1. The procedure described for reconstruction of a useful hand after loss of a central finger or the thumb has been carried out twenty-seven times with slight modification. Various tendon transplantations and grafts were frequently done at the same time. The method consists in transposing the adjacent finger and metacarpal into the defect, thus restoring the parallel alignment of the remaining fingers. In loss of the ring finger, the fifth metacarpal is transposed to the base of the fourth metacarpal. When the long finger is missing, the second metacarpal is transposed to the base of the third metacarpal.

2. The method described for reconstruction of the thumb after amputation consists in transposing the index finger to the first metacarpal, after shortening the index finger to the proper length; then rotating it to the proper position for opposition, and maintaining its blood and nerve supply and tendon control.

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Note: Dr. Walter C. Graham, Dr. J. Barrett Brown, and Dr. Bradford Cannon have returned to civilian practice. Their addresses will be found on page 45 (Advertising).

THE HIGH GEOMETRIC OSTEOTOMY, WITH ROTATION AND BONE GRAFT, FOR UNUNITED FRACTURES OF THE NECK OF THE FEMUR

A Preliminary Report *

BY JAMES A. DICKSON, M.D., CLEVELAND, OHIO

From the Cleveland Clinic, Cleveland

In planning the treatment for ununited fractures of the neck of the femur, orthopaedic surgeons have come to think in terms of a bone-grafting procedure *versus* an osteotomy. This "either-or" viewpoint has been expressed, in a recent collective review [29] on the subject, as follows: "The condition may be relieved by the Albee bone grafting operation, or a modification of this procedure by the insertion of internal fixation in addition to the bone graft. The alternative is to perform one of the various types of osteotomies that have been recommended."

The fact that two schools of thought exist as to the best treatment for ununited fractures of the femur is sufficient evidence that neither procedure in itself is entirely satisfactory. Both procedures—bone-grafting and osteotomy—have produced satisfactory results in a certain proportion of cases, and both present certain advantages and disadvantages. The experience and preference of the surgeon has determined which method would probably offer the individual patient the best chance of obtaining a functioning hip.

Bone-grafting procedures, either alone or together with internal fixation, have been described by Albee, Henderson, Gallie, Compere, Campbell, and the author. These procedures rely largely upon the stimulation of osteogenesis to procure union. In the various types of osteotomy, as devised by Schanz, McMurray, and Leadbetter, and as reported by Schumm, Speed and Smith, Blount, Reich, and others [12, 18, 19, 21, 25, 27], attention has been focused on the correction of faulty mechanics. Although osteotomy has produced satisfactory union in some cases, there have been others in which union did not occur, despite correction of the mechanical difficulty at the fracture site. In a series of thirty patients who were subjected to osteotomy by Speed and Smith, solid osseous union was obtained between the head and the neck of the femur in only fifteen. These authors have commented that, "Although functional results are better if union takes place between all three fragments, or between the head and neck, satisfactory function ensues even though nonunion between the head and neck persists, since the new mechanics of the hip have eliminated shearing force at the fracture site, established a bony support, and provided an improved line of weight-bearing".

The Brackett operation [4], which also aims at correction of faulty mechanics, is still favored by some orthopaedic surgeons [24, 30]; but the author is in accord with the opinion of Watson-Jones that this operation is not to be recommended, because the extensive dissection required produces much greater interference with circulation than does osteotomy.

It has been well established, in the treatment of non-union or delayed union elsewhere in the skeletal system, that good mechanical factors, combined with the use of transplanted bone, yield the most satisfactory results. In studying the problems presented by ununited fractures of the neck of the femur, and in considering the advantages and disadvantages of the various procedures now being used, it seemed desirable that a suitable operation be devised which would combine the advantage of corrected mechanics, obtained by osteotomy, with that of the improved osteogenesis, produced by a bone graft.

* Outline presented at the Annual Meeting of The American Orthopaedic Association, Hot Springs, Virginia, June 29, 1946. Scientific exhibit presented at the Annual Meeting of The American Academy of Orthopaedic Surgeons, Chicago, Illinois, January 1947.

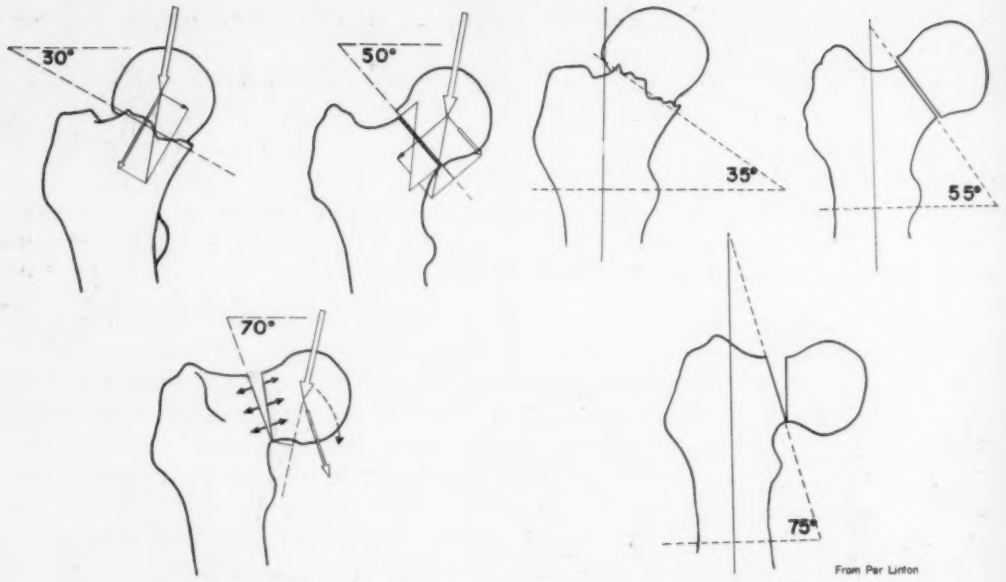

FIG. 1 FIG. 2

Mechanical factors in fractures of the neck of the femur.

Fig. 1: Pauwels' analysis of the plane of fracture. (From Friedrich Pauwels.)

Fig. 2: Linton's analysis of the plane of fracture.

To appraise the mechanical factor, Pauwels made a careful mathematical analysis of the mechanical stresses on the fracture plane in fractures of the femoral neck, occurring at different angles. He has classified these fractures into three groups, according to the angle between the line of the fracture and the horizontal line running through the anterior-superior iliac spine (Fig. 1). If this angle is less than 30 degrees, the fracture is impacting, and will unite soundly with any type of treatment. If the angle is between 30 and 70 degrees, there is less impaction and some shearing strain; the fracture will not unite, unless this shearing force is overcome by internal fixation. If the angle is between 70 and 90 degrees, the fracture line is so nearly vertical, and the effect of shearing stress is so great, that non-union may be anticipated, regardless of whether a Smith-Petersen nail, multiple pins, or the lag screw is used as the method of internal fixation.

Linton, in an analysis of 365 cases of fracture of the femoral neck (Fig. 2), agreed essentially with Pauwels' analysis of the mechanical factors, although he measured the angle of the fracture line in relation to the shaft of the femur, rather than in relation to the horizontal line through the anterior-superior iliac spine. He believed that this furnished a more accurate measurement, since the horizontal line is not always easy to estimate, because, in most cases, a roentgenogram of only one hip is available for study; and the pelvis is, therefore, insufficiently shown to make accurate calculations. Linton stressed the importance of taking the roentgenograms with the limb in internal rotation, in order to procure a free projection of the neck. His method yields angles about 5 to 7 degrees greater than Pauwels', but the results are relatively the same. The author favors Linton's method of calculation as being more accurate, since it is not affected by the adduction or abduction of the limb.

Study of end results after various procedures of osteotomy would seem to indicate that one of the principal difficulties encountered is lack of definite control over the head of the femur and the upper trochanteric segment, and their proper placement, when the shaft of the femur is displaced medially. In many instances, the head of the femur is not rotated sufficiently, and the fragments are not correctly placed to facilitate bony union and repair. Reliance has been placed entirely on the impaction of the fragments

to break down the fibrous scar tissue, and there is no opportunity to use grafted bone to facilitate union.

Neither osteotomy nor a bone-grafting procedure restores the loss of limb length which almost invariably is present with ununited fractures of the femoral neck. In the literature, emphasis has been placed almost entirely on obtaining a stable weight-bearing hip, and results are reported as satisfactory, provided that good joint function has been procured, even though there may be one to two inches of shortening of the limb. In the series of thirty cases reported by Speed and Smith, the average shortening after osteotomy was 1.3 inches. Leadbetter, in one of his last contributions, convincingly demonstrated that, with the high osteotomy, greater limb length was obtained than with other types of osteotomy. However, except in early cases, in which the operation was performed

FIG. 3

Roentgenogram of a typical ununited fracture of the femoral neck.

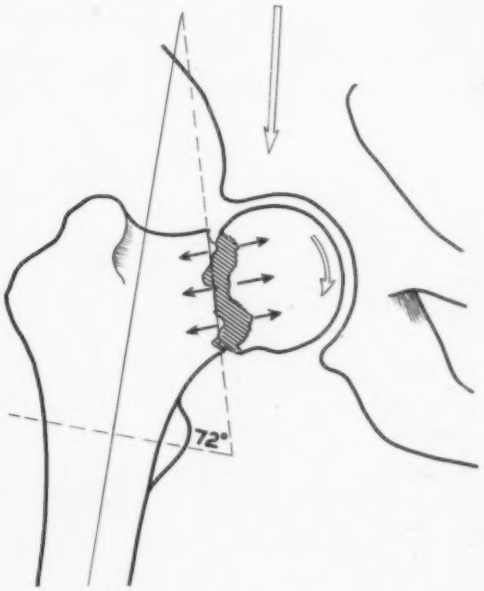

FIG. 4

Mechanical analysis of the fracture shown in Figure 3.

before very much fibrous scar tissue had developed at the fracture site, it was the author's experience that Leadbetter's procedure was carried out only with considerable difficulty.

In analyzing roetgenograms of ununited fractures of the neck of the femur, the femur should always be in internal rotation to reveal the true length of the remaining neck and the inclination of the fracture plane. A review, by the author, of many cases has shown that invariably there has been a downward rotation of the head of the femur, within the acetabulum, of about 60 degrees, and that the plane of fracture has been almost vertical, or, in the terminology of Pauwels or Linton, would fall in the third group (Figs. 3 and 4). It seemed evident on all roentgenograms studied that, if the upper part of the trochanteric region and the head of the femur were rotated 60 degrees, the head of the femur would assume its normal relationship within the acetabulum, and the mechanical stress on the fracture line would be changed, so that the fracture could be classified as in the first group and would have the advantage of impaction to stimulate union.

THEORETICAL TECHNIQUE

After consideration of the above data, the conclusion was reached that an improved technique for the correction of ununited fractures of the femoral neck should consist of a high osteotomy, which would allow a 60-degree rotation of the head and the trochanteric

segment, and that this rotation should be accurately and consistently controlled. This osteotomy, with its mechanical advantages, should be combined with bone-grafting to stimulate osteogenesis, in cases in which this added factor would prove beneficial. The operation should be one which requires a minimum of dissection and of interference with the remaining blood supply to the head and neck of the femur. Shortening in the affected limb should be overcome. In the postoperative treatment, fixation in a plaster cast should be eliminated.

To fulfill these requirements for an ideal procedure for treatment of ununited fracture of the femoral neck, the following technique was planned: It was decided that the trochanteric portion and the head of the femur might be transfixed with a blade plate, penetrating from the lateral prominence of the trochanter into the lower half of the head, to assure accurate control of the head and the trochanteric segment. In anticipation of this 60-degree rotation, the shaft of the blade plate should extend outward at an angle of 60 degrees to the long axis of the femur, so that proper placement of the plate might be readily accomplished after the osteotomy and necessary rotation had been completed (Fig. 5).

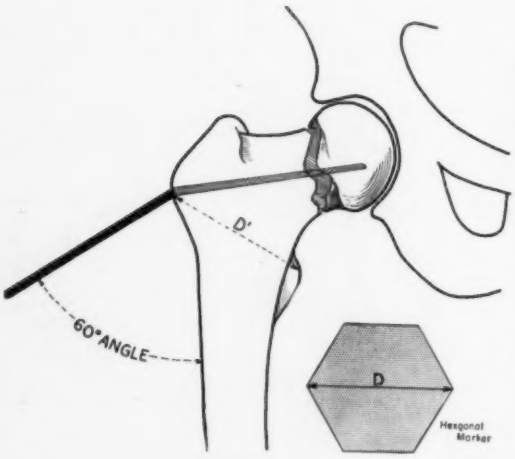

FIG. 5

Transfixion of upper segments with plate at 60 degrees. Drawing shows the method of fixation, the angle of the blade plate, and the estimation of the diameter of the chisel used for marking the site of the osteotomy.

In planning the operation, cognizance was taken of the importance of preserving the remaining blood supply to the head and the trochanteric segment [20, 36, 37]. In exposure of the anterior surface of the intertrochanteric region, the muscles and vessels should be retracted medially, so as to preserve the vascular supply to this region. Osteotomy should then be accomplished with a minimum of interference with the remaining blood supply.

In order to achieve a rotation of 60 degrees that could be accurately and consistently controlled, it was decided that the osteotomy should be made along two sides of what would be a regular hexagon; the fragments could then be rotated by one segment. Hence, it

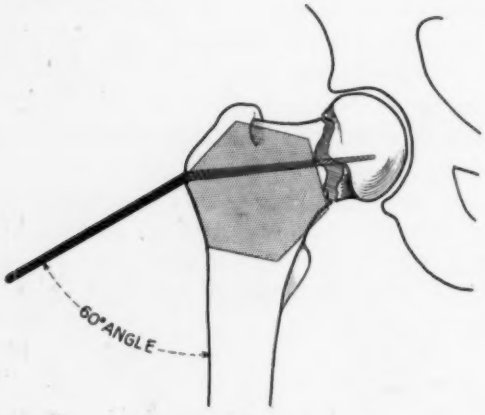

FIG. 6

Drawing showing placement of hexagonal marker to determine the site of osteotomy.

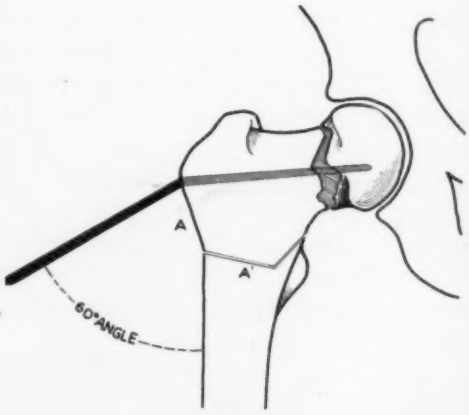

FIG. 7

Drawing showing the osteotomy site.

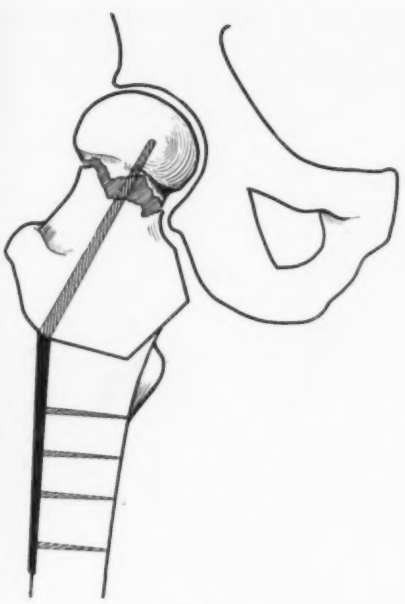

FIG. 8

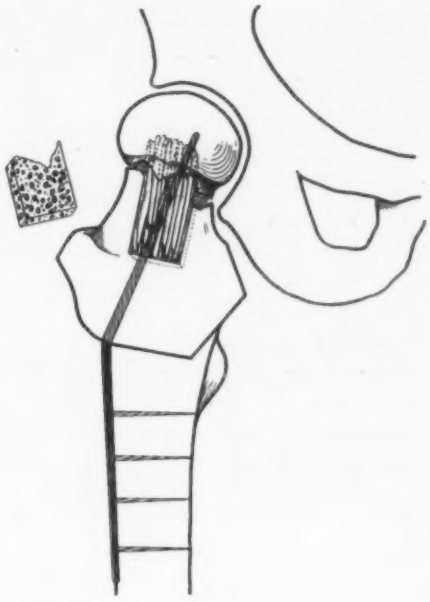

FIG. 9

Fig. 8: Drawing showing rotation of the femoral head and the trochanteric segment, and the fixed position of the blade plate.
Fig. 9: Drawing showing the bone grafts in place.

was necessary to devise a hexagonal marker in which the long diameter of the hexagon equalled the distance from the lateral prominence of the trochanter, where the blade plate entered, to the upper surface of the lesser trochanter (Fig. 5). Then, by placing this six-sided marker on the anterior surface of the femur, with one side parallel to the flare of the trochanter as it extends downward from the site of entrance of the blade plate, it would be possible to determine the exact site for osteotomy (Fig. 6). (In practical application, a semihexagonal chisel is used for this purpose [Fig. 14].) If a marker of the proper size were used, it is obvious that the lower medial edge of the marker would always come out just above the lesser trochanter, thus assuring a high osteotomy. If the upper transfixed fragments were then rotated so that side A would be brought into the position of A' (Fig. 7), an accurate rotation of 60 degrees would be assured; the blade plate would assume its proper position along the shaft of the femur; and a stable contact of the fragments, with a perfect fit, would result (Fig. 8).

To complete the operation, a bone-grafting procedure, designed to ensure osteogenesis, could be readily accomplished by first removing a window from the trochanteric region, and, after thorough curettage of the fibrous tissue from the old fracture site and well up into the head, multiple bone grafts from the ilium could be impacted into the head and neck of the femur, according to a method previously described [13] (Fig. 9).

PRACTICAL TECHNIQUE

The technique used in translating this plan into practice can probably be described best by following the steps as carried out in an actual case.

When necessary, adhesive traction is applied for a few days before operation, to bring the stump of the neck of the femur opposite the head of the bone. In the cases so far encountered, this has been quite satisfactorily accomplished. Some time during the preliminary investigation and preparation, a blade plate of known size is strapped onto the side of the thigh opposite the trochanter, and roentgenograms are made to permit definite calculations as to the actual size of the bone; this determines the dimensions of the blade plate and the marker or chisel which will be used at the operation (Fig. 10).

FIG. 10

FIG. 11

Fig. 10: Preoperative roentgenogram for estimation of actual size of the bone.
Fig. 11: Roentgenogram showing guide wire in place for estimation of position and length of blade plate.

At the time of operation, the patient is placed on the table so that roentgenograms, both anteroposterior and lateral, of the hip are easily made. To accomplish better control of rotation, the limbs are fixed in stirrups with the knees bent. A preliminary roentgenogram is made, so that traction, abduction, and rotation can be adjusted to secure the optimal position.

After the proper preparation and anaesthetization of the patient (with pentothal and inhalation of nitrous oxide and oxygen), an incision, seven or eight inches long, is made on the lateral aspect of the thigh, extending downward from the prominence of the greater trochanter. The outer surface of the bone is exposed subperiosteally, and a bed is prepared for the reception of the blade plate after the osteotomy has been completed. Then, a Smith-Petersen incision is made, as in acetabuloplasty, which exposes the hip joint from the front. The rectus femoris is reflected downward, which allows full exposure of the anterior surface of the femur. The joint capsule is opened, and the incision is carried

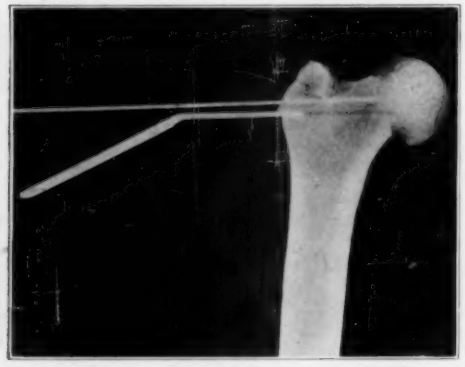

FIG. 12

Fig. 12: Roentgenogram showing the method of determining angulation of the blade plate with a 60-degree protractor.

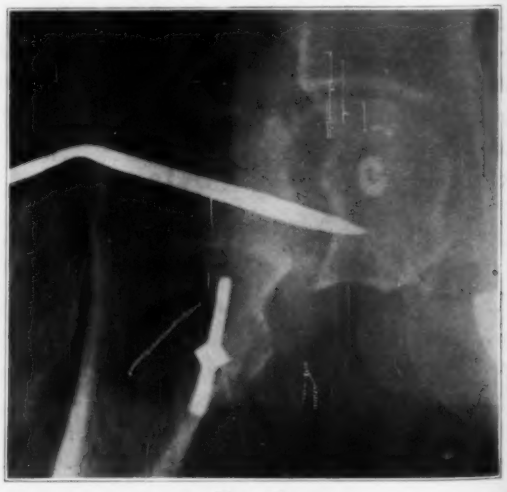

FIG. 13

Fig. 13: Roentgenogram showing insertion of blade plate into the head of the femur.

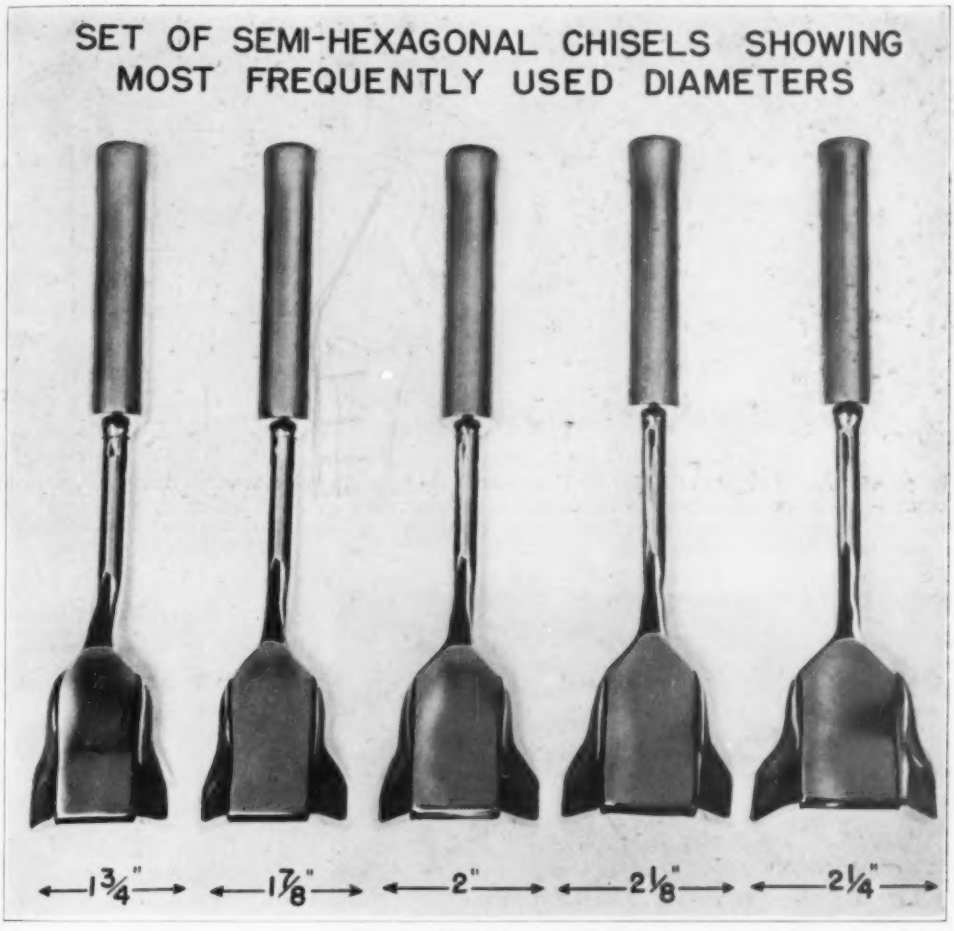

FIG. 14

Set of five semihexagonal chisels for marking the site of osteotomy.

outward, with medial reflection of the muscles anterior to the femur. This allows adequate exposure with a minimum of interference with the blood supply. A guide wire is then passed from a point about one-half inch above the prominence of the greater trochanter into the center of the head of the femur (Fig. 11). Roentgenograms are made in order to check the position of the wire and the length of the blade which will be necessary. The proper blade plate is then selected, and is bent so that, when the blade is inserted parallel to the guide wire, the plate will project from the femur at an angle of 60 degrees (Fig. 12). This angle is procured by use of a protractor [3] which fits along the shaft of the femur. The blade plate is inserted so that a good hold is obtained on the head of the femur (Fig. 13), and the fracture plane is well impacted, and the blade is securely fixed. The lesser trochanter is now palpated, and the distance from the prominence of the greater trochanter, where the blade plate enters, to the lesser trochanter is calculated with a caliper. A semihexagonal chisel, with a diameter of this width, is chosen from the set of five chisels with diameters varying in width by one-eighth of an inch from one and three-quarters inches to two and one-quarter inches (Fig. 14). The chisel selected is then used to mark the site of the osteotomy. One side of the chisel extends down, parallel to the lateral aspect of the femur, from the point of entrance of the blade plate. The line of osteotomy is marked along the other two blades. The osteotomy is completed with an osteotome. The upper end of the trochanter and the head of the femur are then rotated downward, while the femur itself is brought into slight abduction with traction, until the blade plate

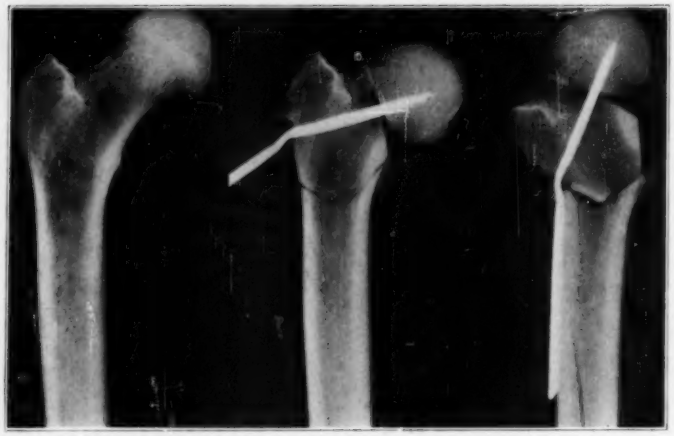

FIG. 15-A

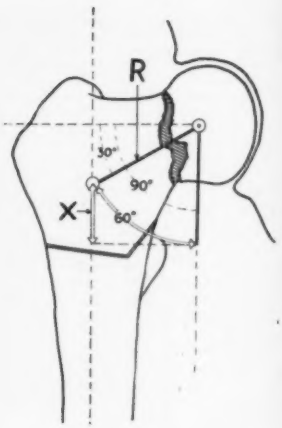

FIG. 15-B

Fig. 15-A: Roentgenogram of femur with ununited fracture and moderate varus deformity, showing equalization of limb length procured by rotation osteotomy.

Fig. 15-B: Moderate varus position with rotation of 60 degrees. Drawing of case shown in Fig. 15-A to show calculation of equalization of limb length.

FIG. 16-A

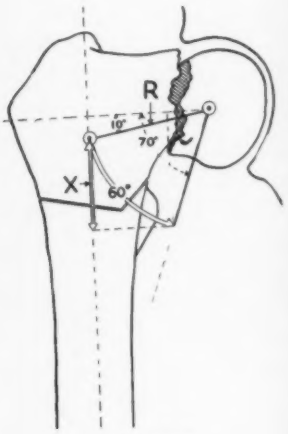

FIG. 16-B

Fig. 16-A: Roentgenogram of femur with ununited fracture and extreme varus deformity, showing equalization of limb length procured by rotation osteotomy.

Fig. 16-B: Marked varus position with rotation of 60 degrees. Drawing of case shown in Fig. 16-A to show calculation of equalization of limb length.

fits accurately along the femoral shaft. The plate is then clamped into position and fixed with screws.

The window is now cut in the trochanteric region, in order to allow removal of fibrous tissue from the fracture plane and curettage into the head of the bone for the reception of the graft from the crest of the ilium [13]. After closure of the capsule, replacement of the muscles, and suture of the wounds, the limb is removed from the stirrup. While the knee is still bent, several firm blows are administered to the knee to assure impaction at the fracture sites.

The limb is now fixed in balanced traction in a Thomas splint. The patient remains in the splint for six weeks, and, during this period, is encouraged to move freely in bed. Treatment after the operation is practically the same as that given after an intertrochanteric fracture in which a blade plate has been used for internal fixation. The author believes that there is a distinct advantage in avoiding external fixation in plaster, especially in the elderly patient, since some movement is helpful in promoting general well-being. While the patient is in balanced traction, quadriceps exercises are encouraged; these tend to

aid impaction of the ununited fracture and at the osteotomy site, and thus help to stimulate bone repair.

EQUALIZATION OF LIMB LENGTH

This type of high osteotomy tends to re-establish a femoral neck, and it increases the limb length from three-quarters to one and one-half inches in the adult of average size. Fortunately, the greater the varus deformity and shortening, the greater the increase in limb length obtained after operation (Figs. 15-A and 16-A). The increase in length can be accurately calculated (Figs. 15-B and 16-B). Rotation takes place about the center of the head of the femur, and the radius of the circle of rotation, designated as R, is equal to the distance from the center of the head of the femur to the center of the hexagon on the trochanteric segment. The degree of varus is determined by the angle that R makes with the perpendicular to the long axis of the femur. When these data are known, the increase in length that will be obtained, when rotation is accomplished, can be calculated by the following formula:

X stands for the increase in limb length.

$$X = R \text{ (Sine of angle after rotation} - \text{Sine of original angle)}$$

The sine values are constant and are easily obtained from tables on the values of trigonometric functions.

In the case shown in Figures 15-A and 15-B, in which a moderate varus position of 30 degrees is present before rotation, the increase of limb length would be calculated as follows:

$$X = R \text{ (Sine } 90° - \text{Sine } 30°)$$
$$X = R \ (1 - 0.5)$$
$$X = R \times 0.5$$

In the case shown in Figures 16-A and 16-B, in which there is an extreme varus position of 10 degrees before rotation, the increase of length would be as follows:

$$X = R \text{ (Sine } 70° - \text{Sine } 10°)$$
$$X = R \ (0.9397 - 0.1736)$$
$$X = R \times 0.7661$$

Thus, in practical application, the rotation of 60 degrees results in restoration of normal limb length.

CLINICAL RESULTS

The clinical results in three cases in which the procedure of high geometric osteotomy, with rotation of 60 degrees and bone-grafting, was performed for ununited fracture of the neck of the femur are presented:

CASE 1. A man, aged forty-two, fractured his right hip in July 1944. He had been treated with supracondylar traction with a Steinmann pin for three months, and then was in a plaster spica for six months. When he first consulted the author, a year and nine months later, there was an ununited fracture of the neck of the right femur, with one and one-half inches of shortening in the limb (Figs. 17-A and 17-B). Operation was performed on May 15, 1946, and balanced traction was applied until June 22. He was walking on crutches in July. Eight months after operation (Figs. 17-C and 17-D), roentgenograms were made which showed that bony union was complete. The patient's lower extremities were of equal length, and he had a full range of motion in the hip joint.

CASE 2. A man, aged fifty-eight, fractured his right hip in February 1943. Internal fixation with a Smith-Petersen nail was instituted four days after injury. Since then, he had not been able to walk without crutches. When he was first examined, on April 17, 1946, three years and two months after the injury, roentgenographic study showed an ununited fracture of the neck of the right femur, with one and one-quarter inches of actual shortening of the limb (Figs. 18-A and 18-B). Operation was performed on July 11, 1946, and balanced traction was applied until August 24. The patient was on crutches two weeks later. When he was seen six months after operation, roentgenograms showed that bony union was taking place

FIG. 17-A

FIG. 17-B

CASE 1. Preoperative anteroposterior and lateral roentgenograms, showing non-union.

(Figs. 18-C and 18-D). The patient had a full range of motion in the hip, and his limbs were of equal length.

CASE 3. A woman, aged seventy-five, slipped on a cement floor and injured her right hip on April 4, 1945. Roentgenograms were made at the time of the injury, but were reported as showing no fracture. When she was seen, three months after the injury, there was severe restriction of motion in the hip joint, with one inch of shortening of the extremity. A roentgenogram revealed an ununited fracture of the neck of the right femur (Fig. 19-A). Operation was performed on August 9, 1945, and balanced traction was applied until September 27. Roentgenograms made nine months after operation showed union of the fracture (Figs. 19-B and 19-C). The patient had an excellent range of joint motion, and was walking well, with limbs of equal length.

FIG. 17-C

DISCUSSION

Despite the great improvement in the results of treatment of acute fractures of the neck of the femur, since the advent of the method of internal fixation[33], non-union results in approximately 20 per cent. of cases,

FIG. 17-D

Anteroposterior and lateral roentgenograms eight months after operation.

FIG. 18-A

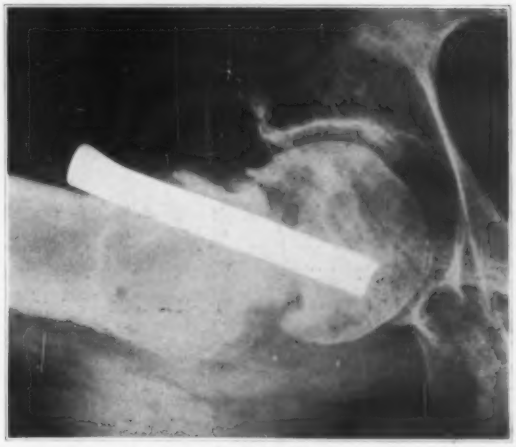

FIG. 18-B

Figs. 18-A and 18-B: CASE 2. Preoperative anteroposterior and lateral roentgenograms, showing non-union.

Figs. 18-C and 18-D: Anteroposterior and lateral roentgenograms six months after operation.

FIG. 18-C

FIG. 18-D

regardless of the type of internal fixation used. The majority of these cases of non-union occur in fractures of the shearing type, in which, as Pauwels has emphasized in his classification of femoral-neck fractures, the plane of the fracture is relatively vertical,—that is, 50 to 90 degrees. By the use of the high geometric osteotomy here described, with rotation of the fragment through 60 degrees, this angle is reduced to 30 degrees or less; thus shearing stress is relieved, and the fracture becomes stable and in the optimal position for bone repair.

By thus correcting the mechanical defect contributing to the non-union, and by further ensuring bony union through use of a bone graft, this method offers definite advantages over those previously employed. Although the procedure has been used in only ten cases—and in some of these the operation has been performed too recently to allow final conclusions—the results so far achieved indicate that actual experience will confirm these advantages.

FIG. 19-A

FIG. 19-B

Fig. 19-A: CASE 3. Preoperative anteroposterior roentgenogram, showing non-union.
Fig. 19-B: Anteroposterior roentgenogram nine months after operation.

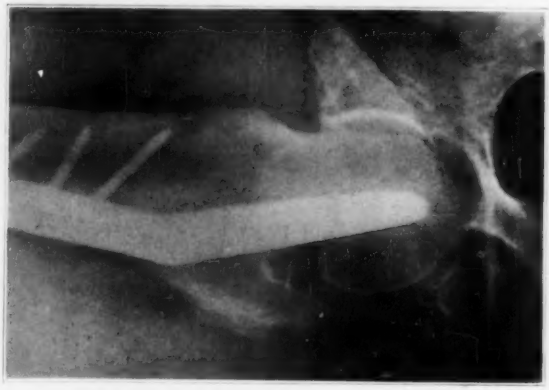

FIG. 19-C

Lateral roentgenogram nine months after operation.

(1) In addition to accurate control in correcting the mechanical defects and (2) to stimulating osteogenesis by use of a bone graft (thus counteracting the two factors most disadvantageous for bony union), the operation also has the following virtues: (3) Equalization of limb length is procured; (4) muscular attachments to the trochanter are not disturbed, and thus the muscles and ligaments are in good position for normal walking; (5) no extensive dissection is required which would cause additional interference with the blood supply to the femoral head and neck; (6) the surgical procedure is not particularly productive of shock; (7) there is no need for external fixation in a cast; and (8) the postoperative care is simplified, involving no greater difficulty than treatment of a simple intertrochanteric fracture in which internal fixation has been used.

It is not as yet definitely established what part the obliquity of the fracture line plays in the development of pseudarthrosis. The fact that, in the cases here presented (in which non-union had persisted for approximately two to three years), bony union was procured after correction of the mechanics is suggestive that this factor is extremely important. Although the author has had no opportunity to apply this geometric osteotomy in treatment of acute fractures, it seems probable that the principles utilized in the treatment of ununited fractures may later be applied in carefully selected cases to prevent non-union. If the possibility of non-union is recognized early, and if the operation is carried out

before advanced degenerative changes have occurred, satisfactory union can be expected, with avoidance of many secondary plastic, reconstruction operations.

Linton, after a thorough analysis of 365 cases of fracture of the femoral neck, concluded that "primary osteotomy in connection with reduction and nailing is indicated in cases with a very steep fractured surface . . . or when, for some reason or other, reduction and nailing have failed". He used a wedge osteotomy as a primary procedure in four cases of the former type; union was obtained in all. The type of osteotomy described in this paper would probably have the same advantages over the wedge osteotomy, for this type of fracture, that it has in old ununited fractures. In acute fractures, the additional feature of the bone graft may not be necessary.

It would seem desirable that additional studies should be made to determine the importance of the angle of the fracture plane in relation to non-union of femoral-neck fractures, and that attempts should be made to prevent pseudarthrosis by attention to this factor. If, by proper selection of cases, osteotomy as a primary procedure could prevent the majority of cases of non-union, this would constitute a distinct advance in orthopaedic practice, and would be a great boon to many patients with fractured hips, by minimizing a long period of incapacity and hospitalization.

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BACKWARD DISPLACEMENT OF FIFTH LUMBAR VERTEBRA IN DEGENERATIVE DISC DISEASE

The Significance of the Difference in Anteroposterior Diameters of the Fifth Lumbar and First Sacral Vertebrae

BY CAPTAIN GILBERT H. FLETCHER

Medical Corps, Army of the United States

From the Veterans Administration, Pittsburgh Regional Office, Pittsburgh, Pennsylvania

Posterior displacement of the fifth lumbar on the first sacral vertebra, interpreted as a posterior subluxation of the lumbosacral joint, received little attention until 1929, when Hibbs and Swift reported the results of operations in six cases. Williams and Yglesias stated that this condition is associated with lumbosacral facets in the frontal plane. In 1934, Johnson and Smith classified posterior displacement as an independent entity, and emphasized its importance in the causation of backache and sciatica. In 1944, Knutsson showed that it was a sign of instability of the lumbosacral junction, associated with disc degeneration. Willis, in 1935, concluded that actual backward displacement does not occur, but is only an optical illusion, due to a relative anteroposterior shortening of the body of the first sacral vertebra.

In the present study, the author will demonstrate that posterior displacement of the fifth lumbar on the first sacral vertebra is a definite pathological occurrence. It is not a separate entity, but is a mechanical consequence of degenerative disc disease. It is also proposed to show that the difference in size of the fifth lumbar and first sacral vertebrae has an etiological significance in the production of these degenerative changes.

This study is based upon 600 roentgenograms of the spine, taken on male subjects in the Medical Department of the Veterans Administration, Pittsburgh Regional Office. These patients are veterans of World War II, most of whom were discharged for backache only; a small number had other unrelated disabilities. In most cases the Service records, containing complete medical histories with roentgenographic and laboratory studies, were available.

Almost 90 per cent. of the 600 veterans were less than forty years of age, as is shown by the following figures:

Under 20 years	1.9 per cent.
21 to 30 years	48.8 per cent.
31 to 40 years	37.8 per cent.
41 to 50 years	11.5 per cent.

The universal symptom was backache, most often in the low back; limitation of motion and sciatica were commonly associated complaints. All of the roentgenograms were taken with the patients in the recumbent position.

In this group of 600 cases, there were fifty-six spines in which there was posterior displacement, of at least 4 millimeters, of the posteroinferior border of the fifth lumbar vertebra in relation to the posterosuperior border of the first sacral vertebra (Figs. 1-A and 1-B). Those cases with displacement of less than 4 millimeters were not included, because of the possibility that such a slight malalignment might be due to technical factors or to individual evaluation. These fifty-six cases represent about 10 per cent. of the group; this figure is in accord with the findings of Johnson.

Willis, in thirty-three of fifty skeletons, found a difference in the anteroposterior diameters of the fifth lumbar and first sacral vertebrae, ranging from 1.5 millimeters to 6 millimeters. He attributed this difference to the fact that the posterior surface of the

FIG. 1-A

Roentgenogram shows posterior displacement of fifth lumbar on first sacral vertebra.

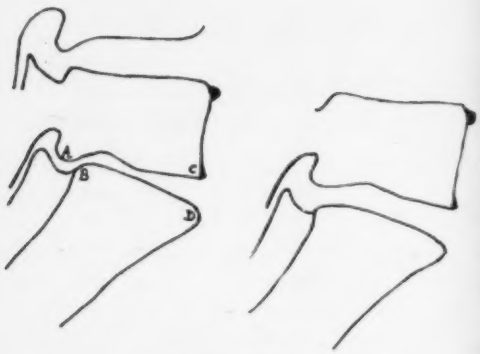

FIG. 1-B

First view is tracing of Fig. 1-A. *A-C* equals 5.1 centimeters; *B-D* equals 4.5 centimeters. Apparent displacement is 9 millimeters. Difference in anteroposterior diameters equals 6 millimeters. Actual backward displacement is 9 minus 6, or 3 millimeters. Narrowing of the disc and umbilication on the posterior aspect of the lower surface of the fifth lumbar vertebra are seen. Second tracing shows the reduction.

FIG. 2

I represents lower surface of fifth lumbar vertebra, and *II*, upper surface of first sacral vertebra. In *III*, the anterior halves of the contours are superimposed, but not the posterior halves. The continuous line represents the concave posterior border of the first sacral, and the broken line, the convex posterior border of the fifth lumbar vertebra.

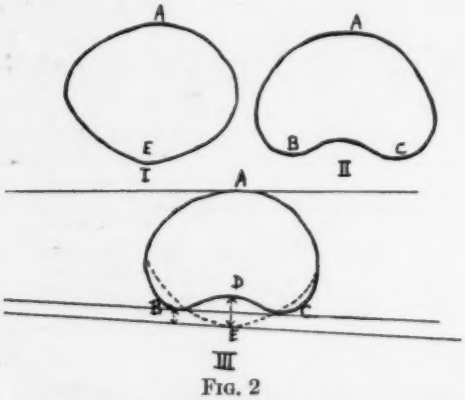

FIG. 2

A: Superimposed anterior borders of fifth lumbar and first sacral vertebrae.
B and *C:* Posterolateral borders of first sacral vertebra.
E: Posterior border of fifth lumbar vertebra.
D-E: Difference in diameters, as measured on skeleton.
B-E: Difference between projections of posterior borders, as seen on the roentgenograms.

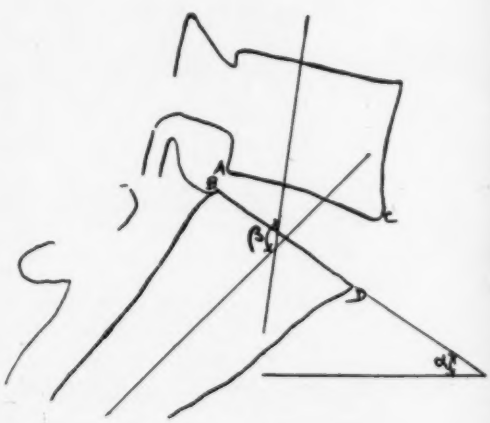

FIG. 3

A-B equals width of the posterior margin of the disc.
C-D equals width of the anterior margin of the disc.
α represents lumbosacral angle Type I.
β represents lumbosacral angle Type II.

sacral body is concave and that of the fifth lumbar body is convex (Fig. 2). He then stated that the relative shortening of the first sacral vertebra gives the illusion of an apparent displacement, and concluded that, if careful measurements of unselected skeletons demonstrate a difference in anteroposterior diameters six times as often as roentgenograms do on patients having back symptoms, this finding can have no clinical significance.

Roentgenograms do not show the projection of the true anteroposterior diameter of the first sacral vertebra but, instead, that of the distance between the anterior and posterolateral borders (Fig. 2). This distance is greater than the anteroposterior diameter in concave vertebral bodies. Obviously, Willis found a higher incidence of lesser anteroposterior diameters of the first sacral vertebra than one would by measuring, on the roentgenograms, the distance between the anterior and posterolateral borders. In this paper the term "anteroposterior diameter" will be used to denote the distance between the anterior and posterolateral borders on the roentgenograms, but one should remember that this is not the true diameter.

The amount of displacement and the differences in diameters (Fig. 1-B) were computed in the fifty-six cases; the averages were 6.7 millimeters and 3.5 millimeters, respectively (Table I). In eight instances, the difference was about equal to the apparent displacement. On the other hand, in seven instances, there was no difference in diameter (Fig. 6), and in the forty-nine remaining cases (87 per cent.), the difference was at least 2 millimeters.

From the total group with backache, of 200 unselected cases without backward displacement and with no other lumbosacral abnormality except occasional spina bifida, the diameter of the fifth lumbar vertebra was on the average only 0.5 millimeter more than that of the first sacral vertebra, with a maximum of 3 millimeters. In about 50 per cent. of the cases, the diameters were equal; and in 10 per cent., that of the first sacral vertebra was slightly greater than that of the fifth lumbar vertebra. A difference in diameters between the fifth lumbar and first sacral vertebrae was found in 87 per cent. of the cases with backward displacement, and no appreciable difference was found in the control group.

In the total series of 600 roentgenograms, thirty-nine cases of advanced degenerative disc disease were found, twenty of which were located at the lumbosacral disc; the others were found at various levels of the spine. This diagnosis was made in the presence of a narrow disc, associated with various degrees of sclerosis, hypertrophic changes, umbilications on the lower surface of the fifth lumbar vertebra, and subdislocation of the facets. The twenty cases of this condition were carefully differentiated from those in which the uniformly narrow disc was seen between a transitional vertebra and the sacrum.

Seventeen of the twenty cases of degenerative lumbosacral disc disease were in the group with backward displacement, and three occurred among the remaining 544 cases. This means that 85 per cent. were associated with backward displacement, and that 30 per cent. of the patients with backward displacement had disc disease. The incidence of lumbosacral disc disease in the group without backward displacement was only 0.5 per cent.

TABLE I

COMPARISON OF FINDINGS IN GROUP WITH BACKWARD DISPLACEMENT AND IN CONTROL GROUP

	Group with Backward Displacement (56 Cases)		Control Group (200 Cases)	
	Mean	Range	Mean	Range
Amount of displacement	6.7 mm.	4 to 10.5 mm.	0	0
Difference in diameters	3.5 mm.	0 to 8 mm.	0.5 mm.	1 to 3 mm.
Posterior disc width	3.5 mm.*	0 to 7 mm.*	6 mm.	0 to 11 mm.
Anterior disc width	17.7 mm.*	13 to 23 mm.*	17.3 mm.	10 to 28 mm.
Lumbosacral angle Type II	136°	115° to 149°	137.8°	110° to 155°
Lumbosacral angle Type I	39°	23° to 60°	44°	19° to 70°

* The 17 cases of advanced degenerative disc disease are not included.

TABLE II

CORRELATION OF DEFINITIONS OF LUMBOSACRAL ANGLES TYPE I AND TYPE II IN THE CONTROL GROUP

Lumbosacral Angles	No. of Cases	Per Cent.
Both normal	56	28
Both abnormal (to some degree)	8	4
Both abnormal (marked discrepancy in degree)	26	13
One normal, the other abnormal	110	55
Totals	200	100

This close correlation between degenerative disc disease and backward displacement is further emphasized by the fact that, in the remaining thirty-nine cases of backward displacement without advanced disc disease, the width of the posterior aspect of the disc was found to be markedly narrowed. The average anterior and posterior widths were 17.7 millimeters and 3.5 millimeters, respectively (Fig. 3). In eleven instances (28 per cent.), the lower surface of the fifth lumbar vertebra actually rested upon the posterior edge of the first sacral vertebra (Figs. 4-A and 4-B). In ten instances, deep umbilications were present on the posterior half of the lower surface of the fifth lumbar vertebra, indicating breaks in the fibrocartilaginous plate.

In the control group, the average anterior and posterior widths were 17.3 and 6 millimeters, respectively. In only two instances (1 per cent.), were the posterior borders in contact.

A comparison of these figures (Table I) shows that the anterior aspect of the disc is not affected, but that the posterior aspect is markedly narrowed. This narrowing has been considered by many authors as indicative of degenerative changes in the posterior fibers of the annulus fibrosus. The writer thought that the lumbosacral angles should be compared in the study group and in the control group to find out whether or not there was a correlation between a narrowed posterior aspect of the lumbosacral disc and an exaggerated lumbosacral angle.

To investigate this point, two definitions of the lumbosacral angle were used because, as far as the author knows, it has not been determined which more accurately depicts the mechanics of the lumbosacral joint (Fig. 3). In the first definition (lumbosacral angle Type I), the angle between the upper surface of the sacrum and the horizontal is measured, the upper limit of normal being given as 42 degrees [4, 12]. In the second definition (lumbosacral angle Type II), the angle between the axis of the sacrum and the axis of the fifth lumbar vertebra is measured, the lower limit of normal being given as 130 degrees[1]. According to these limits, 55 per cent. of the control group had abnormal Type I angles

TABLE III

TYPES OF LUMBOSACRAL FACETS IN THE CONTROL GROUP

Type of Facet	No. of Cases	Per Cent.
Frontal	137	68.5
Oblique cylindrical	20	10.0
Asymmetrical	36	18.0
Sagittal	7	3.5
Totals	200	100.0

FIG. 4-A

FIG. 5-A

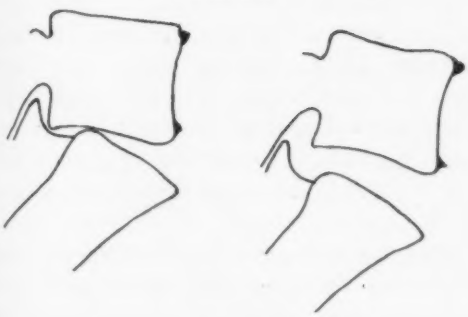

FIG. 4-B

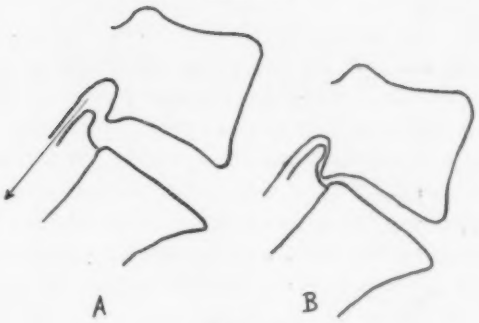

FIG. 5-B

Fig. 4-A: Roentgenogram showing backward displacement.

Fig. 4-B: Anteroposterior diameter of fifth lumbar vertebra equals 4 centimeters; anteroposterior diameter of first sacral vertebra equals 3.5 centimeters. Apparent displacement is 10 millimeters. Difference in anteroposterior diameters is 5 millimeters. Actual backward displacement equals 10 minus 5, or 5 millimeters. The lower surface of the fifth lumbar vertebra is resting on the posterior edge of the first sacral vertebra, with subdislocation of the facets. Second tracing shows the reduction.

Fig. 5-A: Roentgenogram showing backward displacement.

Fig. 5-B: Anteroposterior diameter of fifth lumbar vertebra equals 4.1 centimeters. Anteroposterior diameter of first sacral vertebra equals 4.1 centimeters. Apparent displacement is the same as actual backward displacement, or 4 millimeters. The sacral facets are in contact with the posterior surface of the fifth lumbar vertebra and almost in contact with its pedicles. The tracings show the mechanism of backward displacement. *B* is the tracing of the roentgenogram. *A* is the tracing obtained in giving to the disc its normal width. The arrow shows the direction of the settling of the fifth lumbar vertebra when the disc becomes narrowed, as a result of the interlocking of the facets.

and 8 per cent. had abnormal Type II angles. For a group with backache, the former figure appears too high and the latter figure too low. Table II indicates the lack of correlation. Either the definitions or the values given as normal limits are not adequate.

A comparison of the lumbosacral angles (Type I and Type II) found in both the group with backward displacement and in the control group shows that they are approxi-

TABLE IV

TYPES OF LUMBOSACRAL FACETS IN THE GROUP WITH BACKWARD DISPLACEMENT

Type of Facet	No. of Cases	Per Cent.
Frontal	39	69.6
Oblique cylindrical	5	8.9
Asymmetrical	11	19.7
Sagittal	1	1.8
Totals	56	100.0

mately the same. This clearly demonstrates that the narrowing of the posterior aspect of the disc is not due to an exaggerated lumbosacral angle, and that the explanation for the damage to the posterior fibers of the annulus fibrosus must be found elsewhere.

It has often been stated that lumbosacral facets in the sagittal plane give a more stable joint than those in the frontal plane, and that the most unfavorable situation exists when the facets are asymmetrical,—frontal on one side and sagittal on the other. Actually, the facets are often cylindrical, but in most instances they are predominantly either in the frontal or the sagittal plane. Hibbs and Swift correlated backward displacement with frontal facets, ascribing more laxity to this type of joint; and later Williams described how this is an essential feature in the mechanism of backward displacement. To investigate the correlation between the facet types and backward displacement, their distribution in the control group and in the study group was noted.

In the control group (Table III), facets in the frontal plane are by far the most common and, therefore, must be considered the normal anatomical variety. This seems logical if one considers that the essential role of the lumbosacral facets is to prevent, by their interlocking, anterior slipping.

The distribution of facets in the backward displacement group is shown in Table IV. In the only instance of sagittal facets alone, the apparent displacement was entirely accounted for by the difference in the diameters of the fifth lumbar and first sacral vertebrae. Also, those facets in the cylindrical oblique and asymmetrical categories were predominantly in the frontal plane. It must be remembered that frontal facets of the lumbosacral joint are not strictly in the frontal plane, but are inclined posteriorly (see arrow in Fig. 5-B).

DISCUSSION

From the data presented, the following facts can be stated concerning backward displacement of the fifth lumbar vertebra on the first sacral vertebra:

1. From roentgenograms, the author has confirmed the observations made by Willis from measurements of skeletons,—namely, that there is often a difference in the diameters of the fifth lumbar and first sacral vertebrae. This difference existed in 87 per cent. of the cases with backward displacement, and in practically none of the control group.

2. This difference in diameters was found to account for only about one-half of the apparent backward displacement in 85 per cent. of the cases in this series, thus disproving the suggestion that such displacement is only an optical illusion.

3. Backward displacement is usually associated with degenerative changes in the posterior fibers of the annulus fibrosus and a high incidence of advanced degenerative disc disease.

4. From the facts stated as No. 1 and No. 3 above, we see that there is a correlation between differences in diameters and disc disease.

5. There is no exaggeration of the lumbosacral angle in backward displacement.

6. The lower lumbar and the upper sacral facets are of frontal or predominantly frontal type, and are in a plane directed downward and backward.

The cause of backward displacement lies in the narrowing of the disc. The slipping of the inferior facets of the fifth lumbar vertebra, due to a narrowing of the disc, cannot but take place in a downward and backward direction, carrying the entire body of the fifth lumbar vertebra backward in its relationship to the first sacral segment (Fig. 5-A). Degenerative disc disease or degenerative changes in the posterior aspect of the annulus fibrosus come first, and posterior displacement is a mechanical consequence. The displacement is greater, as demonstrated by Knutsson, when the roentgenograms are taken with the spine in hyperextension; this is due to the fact that hyperextension exaggerates the overriding of the facets and brings out the joint instability.

The amount of displacement will depend upon the obliquity of the facets. This displacement will not be appreciable if the facets are almost vertical (as in the thoracic or lumbar regions), and will reach a maximum for a certain optimum obliquity. The actual backward displacement is the excess of the apparent displacement over the difference between the lengths of the apposing borders of the fifth lumbar and first sacral vertebrae.

FIG. 6

Anteroposterior diameter of fifth lumbar vertebra equals 4.7 centimeters; anteroposterior diameter of first sacral vertebra equals 4.3 centimeters. Apparent displacement is 7 millimeters. Difference in anteroposterior diameters is 4 millimeters. Actual displacement equals 7 minus 4, or 3 millimeters. Deep umbilication is present on the posterior aspect of the fifth lumbar vertebra, and the postero-inferior border of the fifth lumbar vertebra is in contact with the pedicles of the first sacral vertebra.

It has been shown that both a high incidence of degenerative changes in the lumbosacral disc and a shortened first sacral vertebra are found in the group with backward displacement. It has also been seen that, outside of this group, there was no difference in size of the fifth lumbar and first sacral vertebrae, and a very low incidence of disc disease. The incidence of degenerative changes in the annulus fibrosus is no higher in the control group with backache than it was in the series of symptomless males reported by Brav, Bruck, and Fruchter. In both series, the posterior width of the discs was 6 millimeters. This leads to the inference that there is a correlation between a shortened first sacral vertebra and degenerative changes in the lumbosacral disc.

When such a difference in size exists, the posterior border of the fifth lumbar vertebra overhangs that of the first sacral vertebra, so that the posterior fibers of the annulus fibrosus are oblique instead of vertical. This creates an abnormal strain on these fibers, and accelerates the processes of hyalinization and fissuring which take place during life[2,3,4]. This fissuring opens avenues to leakage and dehydration of the nucleus pulposus. The narrowing of the posterior margin results from the degenerative changes in the annulus fibrosus and is followed, as the nucleus pulposus shrinks, by thinning of the whole disc. Therefore, one sees that a shortened first sacral vertebra increases the fragility of the lumbosacral disc in the young adult male.

The comparison of the symptoms in the cases with backward displacement and in the remaining group was striking. Those men with backward displacement of the fifth lumbar vertebra had a much higher incidence of severe low backache, sciatica, and herniated disc

syndromes. Most of the diagnostic and surgical procedures for herniated discs were performed on these fifty-six patients. From the records, it was found that the results of these procedures were not satisfactory; and, at the time of the roentgenographic examination, the symptoms were not improved.

These symptoms are attributed to pressure on the nerve roots in the intervertebral foramina, caused by the narrowing of the foramina and exaggerated, in those cases with backward displacement, by the encroachment of the lower posterior border of the fifth lumbar vertebra. Subluxation of the facets, as discussed by Scott in degenerative disc disease, also plays a role in the production of symptoms (Figs. 5-A, 5-B, and 6).

The differentiation of disc herniation from degenerative disc disease is obviously of great therapeutic importance because, in disc disease, there is no herniated material to remove for the purpose of alleviating pressure on the nerve roots. This explains in great part the poor results after surgery. Instead, it would seem logical, in the presence of disc disease and actual backward displacement, to fuse the lumbosacral joint, with the lumbosacral junction in hyperflexion, in order to reduce the vertebral slipping as much as possible, and to improve the width of the intervertebral foramina.

When the roentgenologist finds a malalignment of the fifth lumbar with the first sacral vertebra, the lower border of the fifth lumbar and the upper border of the first sacral, as well as the amount of malalignment, should be measured. If the malalignment exceeds the difference in diameters, there is actual backward displacement. Careful scrutiny of the apophyseal joints shows overriding of the facets and, eventually, impingement upon the pedicles or laminae. A narrowing of the posterior aspect of the lumbosacral disc is commonly found and its significance is controversial; but, when associated with signs of instability, it can be inferred that degenerative changes are taking place.

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THE PERIPHERAL DISEASE OF POLIOMYELITIS

BY JOHN F. POHL, M.D., MINNEAPOLIS, MINNESOTA

From the Elizabeth Kenny Institute, Minneapolis

Considerable doubt has arisen that the peripheral symptoms of poliomyelitis can be satisfactorily or wholly explained on the basis of the observed pathological process in the nervous system. From clinical studies, there is reason to suspect, in addition, that the disease directly assaults the peripheral tissues of the body. So devastating are the eventual changes in the peripheral structures, and so damaging to locomotion, that it is most necessary to consider every possible origin of such effects and to ascertain the means by which these local changes take place, in order that effective preventive measures may be utilized.

By comparison with the voluminous reported studies of the disease in the nervous system, the peripheral tissues have been practically neglected. The studies of Carey and his associates [1] indicate that motor-nerve endings in muscle may be primarily affected. Knowledge that tissue of the central nervous system has a favorable attraction for the virus of poliomyelitis has beguiled most investigators from serious consideration of the disease process directly affecting the peripheral tissues.

The dearth of objective findings in the peripheral tissues, reported in the literature, does not necessarily prove an absence of primary changes in these parts. It is entirely possible that the methods of study of tissues are still not sufficiently precise to detect changes due to poliomyelitis in these particular tissues. Changes in the skin and muscles escape the pathologist, unless the variations due to pathological changes are remarkable.

Poliomyelitis has long been considered to be a disease basically affecting the central nervous system, with the principal lesion in the spinal cord. Study of the disease has largely been centered about the most easily observed symptom,—weakness or paralysis of the skeletal muscles. Extensive laboratory studies of the disease processes leave little doubt that destruction of anterior-horn cells of the spinal cord may occur, and that permanent motor denervation with paralysis of the correlated muscle units of the body is inescapable in such a case.

Changes in the peripheral tissues have been thought to be entirely dependent upon, and secondary to, the disease in the spinal cord. Not only paresis, but also atrophy, contractures, joint stiffness, leg shortening, circulatory and trophic changes, deformities, and other sequelae were considered to be an unavoidable aftermath of the disease. The spinal cord is relatively inaccessible and its affection unresponsive to any form of therapy known at present.

From a knowledge of anatomy and of the pathology of the nervous system in poliomyelitis, the outlook was definitely not hopeful. As one author recently summed up the situation: "About the only thing that can be done is to let it run its course and then try to patch up the damage".

Based upon the concept that the principal lesion of poliomyelitis is an affection of the central nervous system, the most conscientious efforts in treatment have not prevented a fearful toll of crippled and deformed victims. Poliomyelitis remains the leading single cause of crippling of children in the United States today. It is, therefore, of importance to set down clinical observations upon which possible improvement in methods of treatment may be based.

CLINICAL DATA

A recent contribution to our clinical knowledge of poliomyelitis is Miss Kenny's emphasis upon spasm or hypertonicity as a distinct entity. Whereas paralysis is reported

to exist usually in not more than 50 to 65 per cent. of the cases [2], the hypertonic condition of muscles has been found to be present in 100 per cent. of 1,775 acute cases of poliomyelitis of all types, recently examined.

Hypertonicity or spasm of the peripheral tissues has become recognized as one of the diagnostic manifestations in the disease. This condition, as evidenced by neck stiffness, is the earliest objective finding. Its presence in the posterior spinal muscles and in the hamstrings, long recognized, has been in the past interpreted as evidence of meningeal irritation. The same hypertonicity, differing not in the least in character, may appear in the anterior muscles of the body, as well as the posterior. It may affect any of the muscles, including those with no attachment to the spine.

While it is known that the disease becomes active in the central nervous system, yet the distinctive pain and tenderness in the peripheral tissues are very strongly suggestive of a local process in these peripheral tissues themselves.

The condition of spasm or hypertonicity does not always subside spontaneously, but may go on to cause permanent changes in the affected muscles, consisting of fibroses and contractures. In this respect, the hypertonicity of poliomyelitis is vastly different from that of other conditions. In meningitis there may be extreme hypertonicity of muscle even to the point of opisthotonus, but the muscle disorder always subsides, and the patient becomes flexible as the disease in the spinal cord regresses. From this observation, it may be reasoned that hypertonicity of nerve origin alone does not suffice as an explanation of the permanent muscle shortening which occurs in poliomyelitis. Local changes must apparently also take place in the muscle tissue. This is an extremely important possibility which should be given consideration in all future study of the disease.

The peripheral tissues of the body consist of the skin, the subcutaneous fat, the muscles, and the fascia enveloping the muscles. The symptoms in these tissues in the acute stage of the disease consist of pain, sensitivity, and contraction of the skin; atrophy of the subcutaneous fat; hypertonicity, pain, and shortening of the fascial tissue and muscle; and compression of the muscle. Each of these structures will be taken up in detail, and evidence will be given for the belief that the observed symptoms and findings suggest a local process in the tissue.

SKIN

In many cases, the skin is painful and sensitive in the acute stages of poliomyelitis, and the patient resents palpation. Even the pressure of bedclothes is sometimes uncomfortable. Pinching or stretching the skin is painful. The pain and sensitivity of the skin in the acute stage have commonly been attributed to an inflammatory process in the spinal cord, principally an affection of the sensory posterior nerve roots and the posterior columns of the spinal cord. It is to be noted, however, that the skin may remain tender and sensitive for months, long after the disease must, presumably, have subsided in the spinal cord.

Early in the disease, even in the absence of paralysis, the skin over areas of muscle spasm begins to lose its freedom of movement and to become slightly adherent to the deeper tissues. The skin thickens and, when untreated, in the chronic case is found to be fixed and inelastic. In other cases with paralysis, where there is marked muscle atrophy, there is seldom looseness or wrinkling of the skin, as would be expected from reduced bulk of underlying muscle tissue. Rather is the opposite true,—the skin contracts, becomes thick and unyielding, and loses its soft texture. It becomes agglutinated to the underlying substance and cannot be picked up easily as a separate layer of tissue.

The normal skin has creases or flexure lines crossing the skin at the joint, and the skin is fairly fixed to the deeper structures at these creases. On motion of the joint these creases deepen, and the adjacent skin usually folds over the creases to accompany the movement of the joint. It can be noted fairly early in poliomyelitis that, although the flexure lines remain, the folding of skin adjacent to these creases tends not to appear on flexion of the

joint. This would seem to be the result of an affection of the skin itself, and is presumably due to thickening and loss of elasticity of the skin. This affection of the skin can be observed in areas where there is no muscle paralysis, hence where the associated motor cells of the spinal cord are uninvolved. For this reason, the condition can logically be considered a local disturbance rather than a neurotrophic manifestation.

SUBCUTANEOUS FAT

The subcutaneous fat atrophies quickly in the acute stage of the disease, and some patients appear thinned and almost emaciated within a period of two to three weeks. This is not always a generalized disturbance, but is most apt to appear in areas where there has been definite spasm and hypertonicity. The condition may be especially noticed in the region of the chest, where the skin is observed to become adherent to the underlying bony structure, so that the ribs become very apparent. The chest itself becomes flattened, and the anterior wall of this structure becomes depressed. The condition is not dependent upon paralysis and atrophy of the thoracic muscles, but occurs in many cases in which there is no evidence of paralysis of these muscles. Posteriorly the spinous processes become very prominent as the subcutaneous fat disappears and the skin contracts. The skin here becomes thick and unyielding as the disease progresses.

MUSCLE

The muscle and its enclosing fascia present the most striking evidence of a local process. The hypertonic condition called spasm has been found present in each of these cases of poliomyelitis in the acute stage, and this may affect any of the muscles. The disorder varies in intensity; in some cases there is merely a hypertonicity, but in many cases there is an associated spontaneous pain which may be extremely severe and signalizes an abnormal condition within the muscle. The affected muscle is often exquisitely tender to pressure. The muscle becomes short; attempts to stretch it may be very painful to the patient. This shortening of muscle has often been stated to be a physiological response to weakness of the opposing muscle,—that is, weakness of one muscle upsets the normal balance, so that the supposedly unaffected opponent contracts and shortens. This theory of strong normal muscles pulling against weak ones in the past was further interpreted to explain the contractures and deformities associated with poliomyelitis. It will be noticed, however, that the shortening muscle, which was supposedly normal, is actually tender and painful. A normal muscle should not be painful. Many of these shortened muscles have no voluntary contractile power whatever. Also, it will be observed that the shortening muscle tends to become flattened and narrowed, as if it were becoming compressed, rather than being rounded and bulging, as would occur if this muscle were normally contracting.

The theory of muscle imbalance as a cause of deformity implies that the muscle causing the deformity has retained its motor-nerve supply. This belief does not coincide with the facts, as severe deformity may occur in a limb where there is absolutely no evidence of motor innervation of any of the muscles. Permanent deformities persist when no muscle power returns, and where it must be presumed that the correlated anterior-horn cells of the spinal cord have been destroyed by the disease. A cause other than muscle imbalance must be contrived in order to explain deformity in this circumstance.

It has been observed that the muscle in spasm may remain short after the death of the patient, even in those who die within a few days of the onset of the disease. Mere neurogenic hypertonicity should not cause permanent change in muscle, especially if it is only of brief duration. Thus, even though laboratory proof of the activity of the virus itself in the muscle tissue has not been large in volume, the evidence is highly suggestive from clinical observation that there occurs at some stage of the disease a local process, involving the muscle tissue.

FASCIA

There is reason to suspect that the primary disorder in the shortened muscle in the acute stage of the disease involves the fascial covering of the muscle, as well as the muscle tissue itself. The muscle is enclosed in a tight-fitting sleeve of fascia, which confines the muscle and preserves the normal shape of the muscle. This fascial covering is tough, fibrous, and inelastic, and keeps the enclosed muscle under constant slight tension. It has already been mentioned that a muscle affected by spasm tends to become narrowed and flattened in addition to its shortening. Such a muscle is tender and painful. Any circumstance which would increase the pressure within the fascial envelope, such as swelling of the muscle or shrinking of the fascia, might seriously damage the muscle tissue. Increased tension upon the muscle, for instance by contraction of the enclosing fascial envelope, would interfere with circulation and would deprive the muscle of oxygen. The anoxia or ischaemia would explain the pain in the muscle in the acute stage and the replacement of muscle substance by fibroid tissue later in the disease. Muscles which have been in spasm have the appearance of having been compressed.

More objective evidence of the possibility of direct involvement of fascia by the disease is that certain of these tissues with little or no muscle connection are frequently affected and tend to become short. This has been observed in the case of the iliotibial band of the thigh, contracture of which often causes flexion-abduction deformity of the hip. The plantar fascia of the foot also frequently becomes short, resulting in a highly arched or cavus foot. Such fascial tissues have no known connection with the anterior-horn cells of the spinal cord, and yet they are affected in the disease of poliomyelitis.

EFFECT OF TREATMENT

Evidence of circumstantial nature that the disease attacks the more external tissues of the body is obtained by observation of the effect of treatment applied to the peripheral tissues, on the assumption that the local parts actually are affected. If all of the after-effects of poliomyelitis could really be explained on the basis of the disease process in the nervous system, then treatment applied to the body periphery would have little or no effect upon the eventual outcome of the patient. It is extremely unlikely that such treatment would, to any appreciable degree, interrupt or modify organic disease in the spinal cord, so as to alter materially the effect of a central-nerve lesion upon the peripheral tissues. However, moist heat and other procedures applied to the body surface do relieve pain and do relax the hypertonic structures, with the result that contractures and deformities do not materialize. The blueness, coldness, skin thickening, and excessive perspiration thought due to circulatory changes are prevented, and the common neurotrophic disturbances, such as chilblains and ulcers, are also eliminated by such treatment. The circulatory and trophic changes so frequently observed in the past cannot reasonably be assumed to be due to the action of the disease in the central nervous system, when these deleterious effects can be prevented by treatment of the peripheral tissues.

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FASCIAL REPAIR FOR POLIOMYELITIC PARALYSIS OF THE ABDOMINAL WALL IN ADULTS

BY MAJOR GEORGE T. WALLACE AND CAPTAIN WILLIAM J. WEST

Medical Corps, Army of the United States

From the Army and Navy General Hospital, Hot Springs, Arkansas

Until Lowman brought the subject to our attention in 1932, the importance of abdominal-wall defects as related to infantile paralysis was not recognized. Lowman, in attempting to account for the cause, development, and prevention of scoliosis in this disease, originally reported twelve cases. During the intervening years, many other workers have contributed to this subject. Dickson reported forty-four cases of abdominal fascial repair, and went further in utilizing fascial implants in an attempt to correct cervical scoliosis. He advised attachment of fascial straps from the spine of the scapula to the spines of the thoracic vertebrae or to the origin of the trapezius on the affected side. He also suggested such surgical repair for the loss of the serratus anterior.

Mayer divided patients suffering trunk involvement into three groups. In the first group, were those with development of lumbothoracic scoliosis and a so-called pelvic obliquity, involving unilateral contracture of the quadratus lumborum and the internal and external oblique muscles on the same side, with paralysis of these muscles on the opposite side. If the quadratus lumborum is not paralyzed, a lumbothoracic scoliosis develops without pelvic obliquity, thus constituting a second group of patients. A third group, according to Mayer, were those with bilateral paralysis of the recti abdominis with bilateral weakness of the internal and external oblique muscles, resulting in severe lumbar lordosis and sagging of the abdominal wall. Mayer has followed his cases for a number of years, and it is his conviction that, in severely involved cases, fascial grafting should be performed in conjunction with spine fusion, in order to prevent recurrent scoliosis. He has utilized flat fascial grafts, rather than straps of fascia as suggested by Lowman. It can be stated unequivocally that the integrity of the oblique muscles, as well as of the rectus and quadratus lumborum, is of paramount importance in the development of deformities of the spine, the thoracic cage, and the pelvic bones.

Despite the pioneer work in the use of fascial grafts, the surgical procedure still has not been accepted by all clinics dealing with severely paralyzed patients. Perhaps this hesitance on the part of the orthopaedic surgeon to accept abdominal fascial grafting as a routine part of the armamentarium of surgical procedures in the reconstructive phase of the treatment of poliomyelitis is due to his own inability to recognize the advisability of the procedure. Then, too, some patients are inclined to accept their deformities, and are unwilling to attempt to have them corrected. However, most patients will readily accept any procedure that may offer improvement.

At the Army Poliomyelitis Center, abdominal fascial transplantation is approached from a different point of view than that of the civilian surgeon. It is well known that only occasionally in the adult does abdominal-muscle imbalance cause sufficient spinal curvature to warrant concern. Since all of the patients seen during the War were Army personnel, it necessarily follows that they were all adults before the onset of the disease. Only a small number of patients have had a pelvic obliquity severe enough to warrant a surgical procedure from that standpoint. It is well to bear in mind that the patients sent to this Center manifested severe paralysis which was often generalized. In the majority of our cases, the entire muscular system had been affected to some degree. Those patients with only one or two isolated muscles involved have not been prominent in the total number of cases treated, and have been treated in other Army general hospitals. A recent

analysis of ninety-six poliomyelitis patients in this Hospital, on the basis of abdominal involvement, indicates that twenty-five (26 per cent.) were normal; seventeen (18 per cent.) had mild paralysis; thirty (31 per cent.) had moderate paralysis; and twenty-four (25 per cent.) had severe paralysis. Thus, 74 per cent. had some degree of abdominal paralysis. Although our patients have shown this high percentage of abdominal involvement, not more than 2 or 3 per cent. have had a fixed spinal curve, demonstrable by roentgenograms. Although we have not been primarily concerned with the development of scoliosis, in those patients with severe abdominal involvement, the problem of rehabilitation has been of extreme concern to us. The attempt to render ambulatory a patient who has complete involvement of both legs and abdomen, with or without arm involvement, and to enable him to perform the more simple activities of life, engages the greatest ingenuity on the part of all responsible for his progress.

The Surgeon General has specified that the patients concentrated in the Poliomyelitis Center must reach maximum hospital benefit before being discharged. It has been our aim to try to make these patients as self-dependent as possible. It has long been known that in paralyzed muscles, the greatest degree of improvement in strength occurs within the first six to nine months. Improvement noted thereafter may be due partly to further return of strength in the involved muscles or, more commonly, to the fact that the patient learns to make the best use of his uninvolved muscles and the muscles that have returned to a functional state.

The purpose of this paper is (1) to report twelve abdominal fascial transplantations in nine cases of residual abdominal paralysis, and (2) to show concretely the degree of improvement. We are cognizant of the fact that our group of cases is small compared to the groups formerly reported. We also realize that, in some of our patients who have been discharged more recently, insufficient time has elapsed for full evaluation of the results. Nevertheless, sufficient time has elapsed in most of our cases to give a true picture of improvement. Some of the patients will soon be separated from the Service, and will not be available for further observation. However, it is only logical that, if the patient is showing gradual improvement under our observation, he should continue to improve with no reversals until maximum benefit has been obtained.

Candidates for Surgery

The patients upon whom abdominoplasty has been performed may be divided into two groups on the basis of function. Three patients (Cases 5, 6, and 7) had no strength in the abdominal wall or quadratus lumborum. These might be considered to be in Group III, according to Mayer's classification. All three had severe forward tilting of the pelvis and sagging of the abdominal wall. Cases 1, 2, and 3 might also be considered to be in this same group. The latter group of patients did have some residual strength in the upper portion of the recti and oblique muscles unilaterally, but this strength was of little benefit to them, inasmuch as the lower abdominal wall was completely paralyzed, and there was no transmission of power from the relatively intact upper abdominal wall to the pelvis. Cases 4, 8, and 9 fall into a second group functionally, because in these patients the muscles which elevate the hip were strong enough before operation to allow them to clear the lower extremities with the use of crutches. However, due to loss of stability anteriorly, their balance was extremely poor, and most activities requiring balance were difficult to perform. Neither was there opposition for the serrati to pull against, thus enabling the full use of the good upper extremities.

The complete inability to clear the foot with crutches, as seen in Cases 5, 6, and 7, and also in Cases 1, 2, and 3 to a lesser degree, has been the main indication for abdominal repair. The rehabilitation of these patients has been considerably more difficult than in the second group (Cases 4, 8, and 9). However, even this latter group have shown marked improvement from this procedure, as will be shown on the Improvement Record Chart.

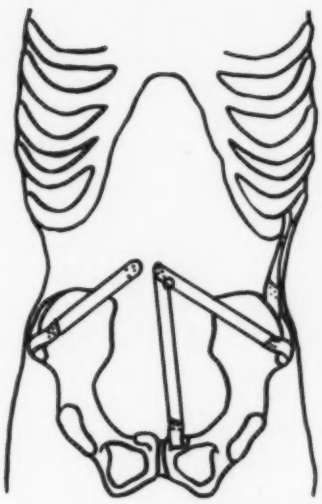

FIG. 1-A

CASE 1. Muscle status and fascial repair.

Right		*Left*
3	Quadratus lumborum	0
4	Serratus anterior	4
3	Erector spinae	3
3	Upper rectus abdominis	4
0	Lower rectus abdominis	0

FIG. 1-B

Right		*Left*
3	Upper obliquus abdominis	3
0	Lower obliquus abdominis	0
5	Upper extremities	5
0	Lower extremities	0

Fig. 1-B: Photograph taken five months after operation, showing how fascial bands assume appearance of strong cords.

The legends for the illustrations explain the individual muscle involvement for each patient we have selected for abdominal fascial transplantation. The figures illustrate anatomically the location of the fascial straps at the time of surgery.

The degree of muscle involvement has been determined by the tests, evolved by Lowman, to demonstrate the degree of paralysis. As Mayer has pointed out, it is markedly difficult to gauge accurately the strength of the muscles in question, because of the inadequacy of knowledge of the kinesiology of these muscles. We have not included in detail the arm and leg involvement, but have only considered the extremities as units.

We have employed the following grading:

0 signifies no contraction felt in the muscle;

1 signifies a trace (the contraction is felt in the muscle, but there is no significant movement of the part);

2 signifies a poor muscle, which moves the part through a partial range when gravity has been eliminated;

3 signifies a fair muscle and one in which the muscle can move the part through a complete arc, the muscle tiring after from three to six contractions;

4 signifies a good muscle, in that it completes the arc against gravity with a medium amount of resistance several times without showing fatigue, but this muscle tires quickly or is unable to complete the arc against maximum resistance;

5 signifies a normal muscle, in that the muscle completes an arc against gravity, and will accept maximum resistance several times without showing signs of fatigue.

SURGICAL TECHNIQUE

Preoperative Care

Patients with abdominal paralysis not infrequently are unable to indulge in sufficient physical activities to maintain their weight at a minimum degree for their stature. In

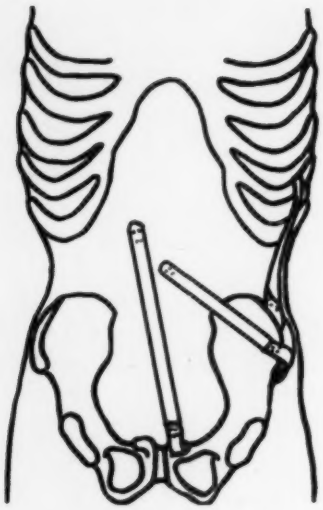

FIG. 2

CASE 2. Muscle status and fascial repair.

Right		*Left*
3	Quadratus lumborum	0
4	Serratus anterior	4
2	Erector spinae	2
0	Upper rectus abdominis	0
0	Lower rectus abdominis	0
3	Upper obliquus abdominis	0
0	Lower obliquus abdominis	0
3	Upper extremities	4
0	Lower extremities	0

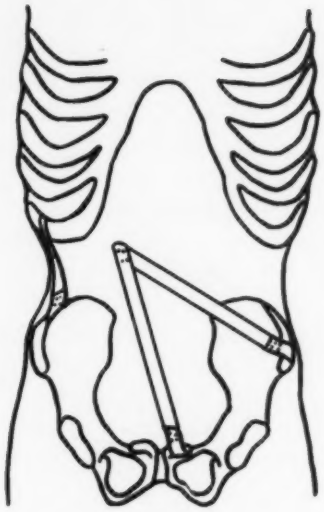

FIG. 3

CASE 3. Muscle status and fascial repair.

Right		*Left*
0	Quadratus lumborum	3
3	Serratus anterior	4
4	Erector spinae	4
4	Upper rectus abdominis	0
0	Lower rectus abdominis	0
3	Upper obliquus abdominis	0
2	Lower obliquus abdominis	0
4	Upper extremities	4
0	Lower extremities	0

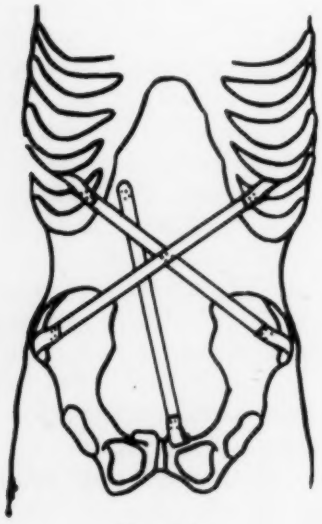

FIG. 4-A

CASE 4. Muscle status and fascial repair.

Right		*Left*
4	Quadratus lumborum	4
4	Serratus anterior	4
2	Erector spinae	2
3	Upper rectus abdominis	0
0	Lower rectus abdominis	0
0	Upper obliquus abdominis	0
0	Lower obliquus abdominis	0
4	Upper extremities	4
0	Lower extremities	3

FIG. 4-B

Fig. 4-B: Photograph taken five months after operation, showing how tightly fascial straps should be inserted in order to accomplish maximum function.

several of our cases, a reduction diet was necessary for as long as two or three months, in order to reduce the patient's weight sufficiently, so that he would be a suitable candidate for this major surgical procedure. Excessive adipose tissue in the abdominal wall only adds mechanical difficulty during the operation.

Prior to operation, each of these patients had a thorough examination from an anaesthetic point of view. Frequently, with abdominal paralysis, the diaphragm is also paralyzed. Such a condition offers a considerable hazard, and the surgeon should appreciate the condition, if it is present, before surgery is contemplated. If any chest complications develop postoperatively, roentgenograms may reveal an elevation of the diaphragm. If there are no preoperative roentgenograms, the surgeon is unable to determine whether the patient had a paralyzed diaphragm preoperatively, or whether the elevation is a secondary complication from the surgery. For this reason, every patient should have a preoperative roentgenogram of the chest.

Nitrous oxide is adequate in the majority of cases, since only first-plane anaesthesia is necessary, and the operation usually lasts two hours or longer. Some patients have needed intratracheal intubation, because of the position required on the table after the fascial transplants have been sutured into place. In these cases it was necessary to employ either pentothal sodium or ether in conjunction with the nitrous oxide to allow sufficient relaxation for the intubation procedure. If there is any paralysis of the muscles of respiration, intubation should be employed. One of our patients (Case 7) had previously had a serious shrapnel wound of the left lung. In this instance, for both operative stages, spinal anaesthesia was used satisfactorily in conjunction with nitrous oxide and pentothal sodium.

Operative Technique

The location of the fascial straps is determined by considering the paralysis in each individual case. In those cases wherein no significant muscle power could be demonstrated in the abdominal wall, anteriorly or laterally, it has been our plan to perform two operative procedures (Cases 4, 5, 6, and 7). The first stage is accomplished by making cross straps from the ninth rib just inside the nipple line to the opposite ilium immediately behind the anterior superior spine on both sides. When the major cross straps have been implanted, we have endeavored to connect them with the anterior rectus sheath cephalad to the umbilicus (Figs. 6 and 8). This is done because the connection above the umbilicus serves as a link, releasing the strain on the transposed fascia. Secondly, should the patient later have a muscle rating of "poor" or "trace" cephalad to the umbilicus, the fascia may then give some resistance to this weakened muscle, if it has been directly connected to it and is not simply overlying it. At the time of the second operative stage, the rib cage and the pelvis are connected laterally from the tenth rib in the mid-axillary line to the crest of the ilium by fascial straps. The latter attachment is either in the mid-axillary line or more posterior, depending upon the strength of the quadratus lumborum. At this time, an additional strap of fascia is utilized to give the paralyzed abdominal wall support in the midline anteriorly from the chondro-osseous junction of the ribs to the opposite superior pubic ramus. This is intended to supplant the work of the rectus abdominis, and to diminish marked lumbar lordosis. It is technically impossible to perform such extensive surgery in one operative stage, as the patient would have to be on the operating table for too long a period of time. We feel that the making of the cross straps in the completely paralyzed abdominal wall should be done first. They are more important structurally than the lateral straps or the anterior strap, and are primarily intended to supplant the trunk-twisting muscles (the obliques, primarily). Also, they give the serratus anterior something to pull against, thus making the upper extremity much more useful to the patient. One operative procedure is sufficient, if only the two long cross straps are to be inserted (Figs. 8 and 9). Similarly, only one operation is necessary if three or four short straps of fascia are needed (Figs. 1-A, 2, and 3).

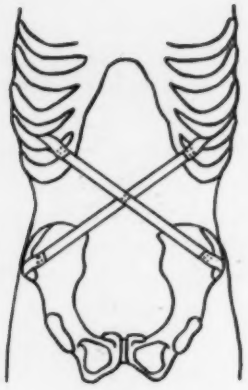

FIG. 5

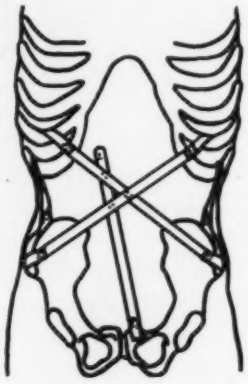

FIG. 6

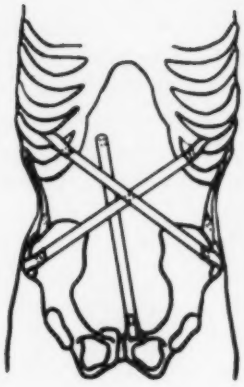

FIG. 7

Fig. 5: CASE 5. Muscle status and fascial repair.

Right		*Left*	*Right*		*Left*
2	Quadratus lumborum	1	0	Upper obliquus abdominis	0
4	Serratus anterior	4	0	Lower obliquus abdominis	0
2	Erector spinae	2	4	Upper extremities	4
0	Upper rectus abdominis	0	0	Lower extremities	0
0	Lower rectus abdominis	0			

This patient is to have fascial straps for quadratus lumborum and recti.

Fig. 6: CASE 6. Muscle status and fascial repair.

Right		*Left*
0	Quadratus lumborum	0
3	Serratus anterior	3
2	Erector spinae	2
2	Upper rectus abdominis	0
0	Lower rectus abdominis	0
2	Upper obliquus abdominis	0
0	Lower obliquus abdominis	0
3	Upper extremities	3
0	Lower extremities	0

Fig. 7: CASE 7. Muscle status and fascial repair.

Right		*Left*
0	Quadratus lumborum	0
4	Serratus anterior	4
3	Erector spinae	3
2	Upper rectus abdominis	2
0	Lower rectus abdominis	0
0	Upper obliquus abdominis	2
0	Lower obliquus abdominis	0
4	Upper extremities	4
0	Lower extremities	0

If the patient is fortunate enough to have some muscle power in the abdominal wall, whether in the upper or the lower quadrants, every attempt should be made to utilize this power; and the straps of fascia should be connected by fascial tunnels from the intact muscle to the bone insertion. When no muscle strength is present, bone-to-bone attachments are used. In any instance wherein bone is used, the tunnel should be covered by a firm bridge of bone. For example, in the ilium an adequate bridge of bone should be present on top of the tunnel to anchor the fascial straps firmly. If good bony anchorage is obtained, physical therapy in the form of rather rigorous underwater exercises can be engaged in with impunity at an early date postoperatively. The most difficult area in which to make a good bone tunnel is the superior ramus of the pubic bone just lateral to the symphysis. A rete of veins is encountered in this area, which, if damaged, may allow blood to collect between the fascial spaces and cause difficulty. Care must be taken, so that damage will not be done to the structures of the inguinal canal.

We have been very liberal with the amount of fascia employed. Previous authors have mentioned that nine-inch straps are sufficiently long to be used as fascial transplants. This is true for the transplants used laterally in the mid-axillary line from the tenth ribs to the crests of the ilia. In all of our cases, however, the cross straps and the anterior strap have had to be from twelve to fourteen inches in length in order to reach satisfactorily the distances required. It is necessary to bring the fascia through the osteoperiosteal tunnels and double the ends back onto themselves before suturing. Moreover, from the cases herein

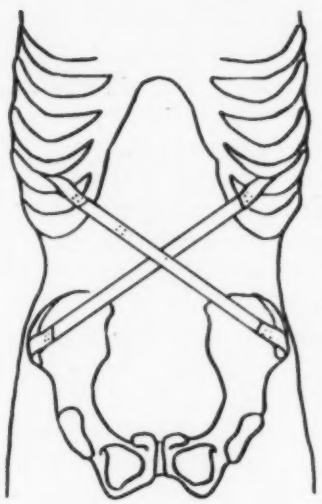

FIG. 8

CASE 8. Muscle status and fascial repair.

Right		*Left*
4	Quadratus lumborum	4
4	Serratus anterior	4
4	Erector spinae	4
4	Upper rectus abdominis	3
0	Lower rectus abdominis	0
2	Upper obliquus abdominis	2
0	Lower obliquus abdominis	0
4	Upper extremities	4
2	Lower extremities	3

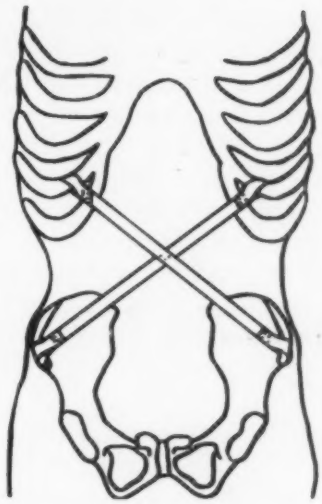

FIG. 9

CASE 9. Muscle status and fascial repair.

Right		*Left*
3	Quadratus lumborum	3
4	Serratus anterior	4
1	Erector spinae	1
3	Upper rectus abdominis	3
0	Lower rectus abdominis	0
0	Upper obliquus abdominis	0
0	Lower obliquus abdominis	0
4	Upper extremities	4
3	Lower extremities	3

presented, it appears that the broader the strap, the more support will be given to the abdominal wall. We have tried to make our straps of fascia one inch or more in width. In order to obtain such liberal quantities of fascia, a separate operating team is employed. Removal of the fascia is performed under direct vision, a long incision being made posterolaterally on the thigh from just below the trochanteric area to the level of the knee joint. In some cases, it is necessary to remove the superficial fibrous sheath of the tensor fasciae femoris superiorly, in order to get sufficient length. Distally, one has to go as far as the deep fascia of the thigh just above the knee joint. If fascia from only one thigh is needed, selection of the donor thigh is determined by the amount of muscle power present. If there is any difference, the weaker extremity is utilized. When the operation must be done in two stages, fascia from both thighs is required. With such a wide strap of fascia removed, it is believed that to attempt to suture the remaining fascia would only cause pain to the patient. Thus in order to repair the donor fascial site, the subcutaneous tissues are closed with interrupted No. 60 cotton sutures, and fine continuous wire is used for the skin, followed by a pressure dressing.

Concerning the fate of this fascia in its new site, it makes no difference whether a tube is made out of it, or whether it is sutured into place as a flat piece. The fascia very soon rolls upon itself, assuming the shape of a strong cord (Fig. 1-B). When one palpates the fascial transplants months later, they are rope-like, rather than flat.

The table on which the patient is placed during the operative procedure is in a flat position, thus allowing more room for the two operating teams.

Skin incisions are made in line with the cleavage of the skin. These incisions heal easily with minimum scar. A five-inch incision is utilized over the selected rib site; an incision of from three to four inches is adequate for the ilium; and an incision of from four to five inches, made in a circular fashion about the umbilicus, gives excellent exposure for the

work about the anterior abdominal wall. The lumbar spine is acutely flexed by placing the operating table in a V position, when the operator is ready to anchor the straps. In this way, the fascial straps are anchored with No. 9 cotton sutures as tightly as possible. The more tension that can be placed on these fascial straps, the easier it will be for them to perform their function (Fig. 4-B). The only exception to this rule is when the erector spinae are weak. It is unwise to deprive the patient of all of his lumbar lordosis, which he may need in balancing activities. In this event, the straps are anchored snugly, but the lumbar spine is not flexed to such an acute degree. After closure of the abdominal wounds with interrupted No. 60 cotton subcutaneously and continuous wire for the skin, the patient's bed is brought to the operating room, placed in a V position, and the patient is lifted from the table to the bed without allowing any stress to be placed upon the fascial grafts.

Postoperative Care

As soon as the anaesthesia has worn off, the patient is encouraged to cough several times hourly, in an attempt to prevent any pulmonary complications. A pulmonary atelectasis developed in one of our patients (Case 5), but with conservative measures, such as voluntary coughing on the part of the patient and the use of an oxygen tent, he progressed very satisfactorily. No other complications have been noticed in this series.

The following day, a graduate physical therapist resumes bed therapy to the extremities, in order to prevent any contractures from developing during the three weeks in bed. After three weeks of the V position in bed, the stitches having been removed, the patient is transported on a litter to the pool. The flexion of the lumbar spine is maintained by having the patient lie on his side. Underwater therapeutic exercises are begun. After the patient is in the pool, he lies on the plinth, and then tries wig-wag and trunk-rolling exercises with progressive intensity. The buoyancy of the water helps to relieve the weight of the lower legs on the fascial straps, while these exercises are being done. During the first few days, the legs are placed in a rubber ring, in order to prevent stress on the new implants. In this way, an increasing amount of work is placed on these fascial straps, which is sufficient to initiate work hypertrophy. Gradually, more and more is done daily in the therapeutic pool. At the end of the six weeks, the nurses on the ward are instructed to lower the foot portion of the bed gradually. In about a week the bed has been restored to its normal position.

At the end of the six weeks, walking exercises are begun. During the convalescent bed period, the patient's braces have been checked thoroughly, so that there will be no delay in resuming walking exercises, when his bed period is finished. A physical therapist, especially trained in walking exercises, is employed for this purpose. The patient slowly accomplishes more and more, as his uninvolved muscles regain their strength, and as the fascial grafts take over more and more of the work intended for them.

RESULTS

The evaluation of improvement from fascial transplantation to the abdomen is difficult. The main reason for this is probably due to the fact that there are such variations of paralytic involvement in patients who have poliomyelitis. No criteria have heretofore been suggested upon which to base improvement from this operation. At this Hospital, we have tried to formulate an accurate method to judge the degree of a patient's improvement postoperatively. During his convalescent period, a patient with severe involvement must undergo a series of complex activities. To a normal individual, these activities are quite simple; but it requires months and even years for the paraplegic and quadriplegic to master such activities. We have selected seventeen different activities which the paralyzed individual must accomplish with some degree of perfection, in order to make himself independent.

We have consolidated into one chart the preoperative and postoperative accomplish-

IMPROVEMENT RECORD CHART

Case	1	2	3	4	5	6	7	8	9
Age of Patient	30	44	23	22	25	21	22	33	24
Duration of Disease Prior to Transplantation (Months)	26	31	16	6	24	19	9	23	22
Duration of Disease Since Transplantation (Months)	10	9	8	5	4	4	2	3	2
Number of Operative Procedures	1	1	1	2	1	2	2	1	1
Ability to Roll over in Bed	Grade III	Grade III	Grade III	Grade III	Grade II	Grade III	Grade O-b	Grade II	Grade I
Ability to Sit up in Bed	Grade III	Grade III	Grade III	Grade II	Grade II	Grade III	Grade IV	Grade III	Grade O-b
Ability to Get into and out of Braces	Grade III	Grade III	Grade III	Grade III	Grade II	Grade O-b	Grade IV	Grade I	Grade O-a
Ability to Get into and out of Wheel Chair	Grade II	Grade IV	Grade III	Grade III	Grade II	Grade III	Grade O-b	Grade I	Grade II
Ability to Get into and out of Straight Chair	Grade IV	Grade II	Grade III	Grade II	Grade I	Grade O-a	Grade IV	Grade O-b	Grade II
Ability to Dress and Undress	Grade O-b	Grade II	Grade III	Grade III	Grade II	Grade II	Grade I	Grade II	Grade O-b
Ability to Walk in Pool	Grade III	Grade II	Grade III	Grade III	Grade II	Grade IV	Grade IV	Grade III	Grade II
Ability to Walk in Parallel Bars	Grade III	Grade III	Grade III	Grade III	Grade II	Grade O-b	Grade II	Grade II	Grade II
Ability to Walk in Walker	Grade III	Grade III	Grade III	Grade III	Grade II	Grade IV	Grade III	Grade II	Grade III
Ability to Walk with Crutches—Four Point Gait	Grade IV	Grade III	Grade III	Grade III	Grade II	Grade O-a	Grade IV	Grade III	Grade III
Ability to Walk with Glider Canes	Grade IV	Grade III	Grade O-a	Grade O-a	Grade I	Grade O-a	Grade IV	Grade IV	Grade O-a
Ability to Walk with Canes	Grade O-a	Grade O-a	Grade O-a	Grade IV	Grade O-a	Grade O-a	Grade O-a	Grade IV	Grade O-a
Ability to Walk Three-Inch Steps with Rail	Grade IV	Grade IV	Grade III	Grade IV	Grade O-a	Grade O-a	Grade IV	Grade II	Grade O-a
Ability to Recover Objects from Floor	Grade III	Grade III	Grade III	Grade II	Grade I	Grade O-a	Grade IV	Grade O-b	Grade II
Ability to Get onto and off Commode,	Grade IV	Grade IV	Grade IV	Grade IV	Grade III	Grade I	Grade IV	Grade II	Grade I
Improvement of Bowel Function	Grade III	Grade III	Grade O-b	Grade O-b	Grade O-b	Grade O-b	Grade O-b	Grade O-b	Grade II
Balance	Grade III	Grade III	Grade IV	Grade III	Grade IV	Grade III	Grade III	Grade III	Grade III

Grade O-a: Patient could not perform activity before or after surgery.
Grade O-b: Patient could perform activity before surgery, and noted no improvement after surgery.
Grade I: Mild improvement.
Grade II: Moderate improvement.
Grade III: Marked improvement.
Grade IV: Patient could perform activity after surgery, which he could not perform before surgery.

ments of the patient, in so far as his physical aptitude in performing these activities is concerned. The left-hand column of the Improvement Record Chart enumerates these seventeen activities. Each patient has been graded from O to IV on the basis of his ability to perform these functions. This method is subject to criticism because, in many instances, grading of improvement may be influenced by the personal equation either of the surgeon or of the patient. We have endeavored to be as objective in our grading as possible. The gradings represent the combined opinions of all concerned with the patient's welfare. Even the ward master who assists in helping the patient perform his necessary bodily functions has been consulted with regard to his opinion of the patient's improvement. We have interrogated the patient to determine his own impression of his improvement, and have obtained the opinion of the graduate physical therapist in charge of each particular patient daily. Finally, we have added our own deductions concerning the patient's improvement.

If a patient could not perform the particular function before or after surgery, there has been no improvement with respect to that particular activity, and it has been charted as "Grade O, sub-group a". If a patient was able to perform the activity before surgery and noted no improvement after surgery, that has been termed "Grade O, sub-group b". If he has noted that he can perform the particular activity in question with slightly more ease than before, there has been mild improvement and it has been charted as "Grade I". If the particular activity was considerably easier postoperatively, and this has been definitely noticed by all concerned, there has been moderate improvement and it has been charted as "Grade II". "Grade III" improvement has been recorded, when the patient can do something in striking contrast to his preoperative ability. In the latter instance, there is marked improvement in the particular function that is considered. If the patient could do one of these activities after surgery that he could not do before surgery, we have graded him as "Grade IV". Herein lies the accomplishment of a new activity or function that this particular patient can now perform for himself, which was impossible before the operation.

This chart is designed as a gauge of improvement. The grading of the patient has absolutely nothing to do with the degree of perfection with which the particular function is accomplished. For example, the patient (Case 1) can dress and undress without any difficulty whatsoever; however, he could do this with equal ease before fascial transplantation, and therefore falls into Grade O-b. Conversely, the patient (Case 2) may be able to get into the wheel chair now, whereas he could not do so before surgery; however, to get into the wheel chair requires considerable effort at the present time. Nevertheless, since it is an entirely new activity on his part, we believe it should be charted as Grade IV improvement.

One patient was under observation for ten months, which is the longest period of time for our consideration of improvement. The shortest period was two months. The time interval for each case can be observed on the accompanying chart.

None of the patients was impaired by this operative procedure. In an over-all inspection of the chart, one can note that the patients who have shown the most improvement from their operations are those who have been observed longest postoperatively. Those who have been operated upon as recently as two months ago have already shown considerable improvement. Although we believe they will continue to improve more as the transplants become stronger, we are evaluating their improvement at this time, because further follow-up study would be difficult. Their improvement is considered as of the date of this report, rather than as we hope the future improvement will be.

Improvement in balance has been constant in each case after this type of surgery. Each patient has received at least a Grade III improvement in his balance, and two have received a Grade IV improvement. By Grade IV, in this particular instance, we mean that patients now can stand without the use of crutches and balance themselves in leg braces, which was impossible preoperatively.

The second physical function in which all patients have shown improvement is walking. We have subdivided this into ability to walk (a) in the therapeutic pool, (b) with parallel bars, (c) in a walker, and (d) with crutches. Only one of the patients failed to notice improvement in the use of crutches, and he was very severely paralyzed (quadriplegic). He was unable to walk with crutches before the procedure, and four months after the operation this activity was still impossible, and he has, therefore, been graded Grade O-a (Case 6). However, it will be noticed in this case that the patient is now able to walk in the walker, which was impossible prior to surgery. After he has walked long enough to develop sufficient strength in his upper extremities to hold his weight, the patient will undoubtedly be able to walk with crutches. Of the remainder of the patients, two who could not walk with crutches preoperatively are now able to do so, and five have shown a striking degree of improvement in walking with crutches. These patients are placed in the Grade III group. One patient (Case 5) has noticed a Grade II improvement; however, this patient has had only the first-stage operation (cross straps) (Fig. 5), but it is apparent that he will need the second stage for his weak quadratus and recti, in order to gain maximum improvement from fascial transplantation. Three of our patients have been able to walk with glider canes, which they were unable to do prior to the operative procedure. One of them has shown a Grade III, and one a Grade I improvement, with respect to this activity. Four of the patients were not able to use glider canes prior to surgery, and have not been able to use them since surgery. They have, therefore, been placed in Grade O-a. Two of the patients, who needed crutches preoperatively, were able to walk with ordinary canes for the first time after the operation. The remaining seven patients have been unable to use ordinary canes either before or after surgery; and therefore, they are placed in Grade O-a.

One very important improvement which we have observed in all of the patients has been the ability to get on and off a commode. If these patients with severe involvement can handle themselves adequately without assistance in this particular activity alone, we believe that this surgical procedure is well warranted. In our group of patients, five are now able to accomplish this routine without assistance; whereas, before operation, it was impossible. One patient has noticed Grade III improvement, one has noticed Grade II improvement, and two have noticed Grade I improvement, with regard to the use of the commode. Strangely enough, two of our patients no longer show constipation as they did prior to surgery. There was no change in the bladder function, in so far as we could ascertain.

Concerning the ability to get in and out of their braces, seven patients have noticed improvement,—one Grade IV, four Grade III, one Grade II, and one Grade I. One has noticed no change,—that is, he could not do it before and he cannot do it now. This individual has a back brace attached to two long leg braces, and has complete paralysis of both lower legs. The other patient (Case 9) who is in Grade O-a was not graded in this particular activity, since he does not use braces. All of the patients except one have noticed improvement in being able to sit up in bed. Similarly, all except one have noticed improvement in being able to roll over in bed. That one (Case 7) falls into Grade O-b, because he could do it with equal agility before surgery. Eight of the patients have noticed improvement in being able to get into and out of a wheel chair. Only one patient has noticed no change. Seven patients have noticed improvement in their ability to get into and out of a straight chair. One of the other two falls into Grade O-b, and the other into Grade O-a.

Four patients have had sufficient abdominal paralysis to necessitate two surgical procedures, and five have only needed one operative procedure. In Case 5, as mentioned above, only the first or cross-strap procedure has been done; in the near future the second operation will be performed. Owing to the development of pulmonary atelectasis, it was deemed wise to delay the second stage for a few weeks. Usually, however, the second or completion stage is performed three weeks following the first operation.

DISCUSSION

These patients must learn to use their new abdominal support. They must learn how to bring the shoulders back and the thoracic cage up, in order to put maximum tension on the transplanted fascia, and thus bring forward the anterior portion of the pelvis. This action transmits the needed power from the arms, shoulders, and chest to the lower legs through the fascial straps. It takes a considerable length of time to learn how to do this and, of course, depends upon the amount of shoulder and chest involvement present.

It should also be mentioned that, in grading these patients, no attempt has been made to compare them to normal individuals. We cannot grade the results of this operation in terms of normalcy. For the most part, the activities mentioned are not activities in which the unafflicted individual must engage. The actions of a patient who has noticed a striking improvement, due to fascial transplantation, cannot be compared to those of a normal individual in performing the same functions, because the latter does not possess paralyzed extremities. When the nerve supply to the abdominal muscles is no longer intact, nothing will replace normal muscle action, but the fascial transplants do suspend the pelvis anteriorly and laterally in such a way as to assist these patients in making a physical adjustment to life. Furthermore, this method of grading allows ample room for further improvement in these individuals.

It might be considered by some orthopaedic surgeons that inadequate time has elapsed for the use of this procedure in some of these patients,—as those who have had the disease for less than two years. In fact, many authors who have written on the reconstructive stage of infantile paralysis have stated that in the first two years, surgery plays little or no role. We do not feel that this is true, especially in cases of abdominal transplantation. Three of our patients (Cases 1, 2, and 3) had had residual paralysis for two years or longer. No improvement had been noted in the strength of the paralyzed abdominal wall for twelve months or more. We now feel, in retrospect, that progress in these cases was hindered by waiting the additional year or more before surgery was suggested. If it is determined by the surgeon in charge and the physical therapist that the patient has shown no improvement in the strength of the abdominal muscles for a period of three months, it is our belief that this type of reconstructive surgery is indicated. There are many reasons for this belief. If the surgery enables the patient to engage more actively in those functions which are pertinent to his rehabilitation, it allows the patient to develop the muscles which were not involved *per se* in the initial onset of his disease. The atrophy of these muscles is secondary to the bed rest or inactivity, which is brought about by his inability to use his paralyzed abdominal wall or the muscles which elevate the hip in walking and other activities. Several of our patients, for example, were unable to walk with crutches, because of weakness in the arms bilaterally, and also because of failure of the abdominal muscles to connect the trunk with the pelvis. These patients have noticed that since their pelvic suspension surgery they are able to use the walker, and that their arms are definitely getting stronger. This finding is substantiated by our muscle examinations. Furthermore, we think that, if abdominal transplantation is done early enough—that is, during the first six to eighteen months—the suspension of normal, good, or fair upper recti and internal and external oblique muscles to the pelvis will give them a firm attachment upon which they may act and become stronger. DeLorme has clearly demonstrated the importance of resistance in the development of muscle strength. Due to the support of these fascial struts, there has been some return in strength of the paralyzed muscles. This, although minimal, has been observed by the physical therapist on the muscle-grading chart in some of the cases herein presented. In these latter cases, we feel that the support of the fascial straps in holding in the paralyzed muscles and preventing overstretching helps them to regain all the strength they possibly can. A flaccid abdominal wall simply overstretches the weakened muscles, and makes them lose all the strength they might have gained, had one waited until

the arbitrary two-year convalescent period had elapsed before considering surgery. It is true that a simple abdominal support will hold in the paralyzed muscles, but this is only temporary, and the patient has no support when he rests. An adequate support is one that is present at all times in all positions. We consider this fascia as an internal support for weakened muscles.

It is an error to consider this procedure only if all other efforts fail. It has been noted in this Hospital that, after the first few patients had been operated upon, other patients became aware of the postoperative improvement. Subsequently, some have asked if they too might be candidates for a similar procedure.

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Backward Displacement of Fifth Lumbar Vertebra in Degenerative Disc Disease

BY CAPTAIN GILBERT H. FLETCHER

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TRANSPOSITION OF THE ANTERIOR TIBIAL TENDON IN THE TREATMENT OF RECURRENT CONGENITAL CLUB-FOOT *

BY GEORGE J. GARCEAU, M.D., AND K. R. MANNING, M.D., INDIANAPOLIS, INDIANA

From the James Whitcomb Riley Hospital for Children, Indiana University School of Medicine, Indianapolis

The incidence of recurrence of the deformity in congenital club-foot is no doubt inversely proportional to the thoroughness of early conservative treatment. Statistics in the literature dealing with this recurrence vary greatly. Brockman reported that 50.6 per cent. of patients with this deformity required no further treatment after adequate conservative management. Kite stated that 90 per cent. of all club feet could be corrected by wedge casts. Blumenfeld, Kaplan, and Hicks recently reported good results in almost 80 per cent. of their patients who had been treated conservatively.

Of 1,275 patients with club-foot, treated in the James Whitcomb Riley Hospital since 1930, eighty-six (6.7 per cent.) have undergone transposition of the anterior tibial tendon. It would appear from our study that recurrence of the deformity, after apparently complete correction, is due to dysfunction of, or incoordination between, the anterior tibial and the posterior tibial muscles, as invertors, and the peroneal muscles as evertors of the foot. In 1894, Sir Robert Jones stated that congenital talipes (equinovarus) is not cured until the patient can voluntarily place the foot in the position of valgus. Therefore, upon examination of recurrent club-foot, we examine the muscle balance. If the peroneal muscles are weak and supination occurs on dorsiflexion (extension) of the foot, we believe that transposition of the anterior tibial tendon is indicated. In 1923, Naughton Dunn mentioned transplantation of the anterior tibial tendon, but did not report on the subject. The operation to transpose the anterior tibial tendon to the lateral aspect of the foot for recurrence of club-foot deformity was first performed by one of us (G.J.G.) in 1933. In 1940, we reported the end results in forty-four patients and fifty-six feet. Since then we have continued to perform the operation whenever indicated. This study is based on the end results in eighty-six patients and 110 feet, and it includes a re-evaluation of the previously reported cases. This operation was chosen, rather than arthrodesis, transtarsal wedge osteotomy, or other bone-cutting operations.

The average age at the time of operation was six and one-half years. The average duration of active preoperative treatment was 4.8 years. The youngest patient was two and one-half years of age, and the oldest, seventeen years, at the time of operation.

One hundred and thirteen operations had been performed previously on the 110 feet, including lengthening of the Achilles tendon (64), fasciotomy (23), Ober's tendon transplantation (2), Brockman's operation (3), triple arthrodesis (5), transtarsal wedge osteotomy (2), decancellation of the calcaneus (6), and capsulotomy (8). Forceful wrenchings had previously been done on many feet. In each instance, the deformity had recurred two or more times.

This operation is not recommended for correction, but rather for prevention of recurrence of the deformity; however, it does have a corrective influence. In two feet, the anterior tibial tendon was returned to its original insertion to prevent planovalgus deformity. It should also have been done in a third case. Many feet continued to improve for a number of years.

Preoperative preparation of the foot by the wedge-cast method is advised. As much correction as possible should be obtained.

The operation itself consists of transposing the anterior tibial tendon to the proximal

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TABLE I

EFFECT ON THE VARIOUS COMPONENTS OF THE DEFORMITY

	Equinus (*Per cent.*)	Inversion (*Per cent.*)	Adduction (*Per cent.*)
Excellent	64	63	64
Good	21	16	21
Fair	9	14	9
Poor	6	7	6

TABLE II

FUNCTION OF TRANSPOSED ANTERIOR TIBIAL TENDON

	Function (*Per cent.*)	Number of Feet
Excellent	49	54
Good	40	44
Fair	7	8
Poor	4	4
Total		110

end of the fifth metatarsal. If the tendon is too short, it is anchored into the cuboid bone. A cast is worn for at least six weeks after surgery. In most cases, wedge casts are applied every two weeks for two or three months after operation. After discontinuation of the casts, exercises are given to train the transposed anterior tibial tendon.

The effects of the operation on the various components of the deformity are shown in Table I. It is apparent that each component is affected to about the same degree.

The function of the transposed anterior tibial tendon was excellent or good in ninety-eight feet, or 89.1 per cent., of the series.

The end-result study indicates very satisfactory improvement in ninety-one, or 82.7 per cent., of the club feet in the series. In nineteen feet, or 17.3 per cent., the results were not considered satisfactory, although some degree of improvement was noted in each case (Table III). The average period of follow-up was five years. It was over seven years in fifty-six cases.

Twenty-seven operations were performed subsequent to the tendon transpositions.

FIG. 1

W. W., aged seven. Recurrence of the deformity in all its components. *B* and *C* are photographs taken three years after anterior tibial transposition, showing excellent correction.

TABLE III

END RESULTS

	Number of Feet	Percentage
Excellent	67	61
Good	24	22
Fair	9	8
Poor	10	9
Total	110	

One patient tore the tendon at its new insertion, but a good result followed repair. Two tendons were re-anchored to their original insertions with excellent end results. Eight of the ten feet classified as having poor results required bone-cutting operations. The poor results were due to poor correction prior to tendon transposition, rigid feet caused by previous operations, and growth disturbances in the bones of the foot. Poor function of the transposed tendon was a rare cause. In no instance was the operation detrimental.

Frequently, abnormalities were found in the tendons at operation. Separation of the tendon into two or three slips at the insertion was the most frequent finding. Adhesions

FIG. 2

R. W., aged seven. Recurrence of the deformity in all its components. *B* and *C* are photographs taken three years after operation, showing excellent results. About 10 degrees of residual equinus.

FIG. 3

J. W., aged two. Rigid recurrence of all components; deformity was never completely corrected. *B* and *C* are photographs taken one year after operation, showing a fair degree of correction. No further surgery was performed.

to the tendon sheath were noted several times. Fusion of the anterior tibial tendon with the extensor hallucis longus was noted once.

CONCLUSIONS

1. Recurrence of the deformity in club-foot is not infrequent.
2. The faulty mechanism of the muscles everting and inverting the foot may be the cause.
3. Recurrence of the deformity may be prevented by transposition of the anterior tibial tendon in selected cases.
4. This operation is not recommended for correction of the deformity.
5. The transposed anterior tibial tendon may be restored to the original insertion when planovalgus or overcorrection is apparent.
6. Satisfactory results were obtained in ninety-one, or 83 per cent., of the 110 feet so treated.

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DISCUSSION

DR. J. HIRAM KITE, ATLANTA, GEORGIA: The discussion of this paper can be divided into two sections, tendon transplantation and club feet.

First, when should we transplant tendons? In times past, our only indication for transplanting tendons was a gross muscle imbalance, as in poliomyelitis or some injury to the nerve which has completely paralyzed one group of muscles.

There is no gross muscle imbalance in congenital club-foot; it is only an apparent imbalance. In the original untreated club foot, the anterior tibial and posterior tibial tendons are seen to contract, because the fore part of the foot is adducted and the heel is inverted. The tibial muscles are in a shortened position, and the line of pull is such that they work at an advantage. When the club-foot deformity is corrected by any means, the muscles resume a normal balance. When the club-foot deformity recurs, there is again only an apparent imbalance, due to the shortened muscles and line of pull. When the foot has been restored to a normal position, the muscles will be in normal balance.

Dr. Garceau and Dr. Manning say, "If . . . supination occurs on dorsiflexion (extension) of the foot, we believe transposition of the anterior tibial tendon is indicated". Personally, I would not feel justified in operating with so slight an indication.

Second, Dr. Garceau and Dr. Manning have had a very resistant group of recurrent club feet to treat, because of the stiffness and rigidity following the early treatment. They say that 113 operations had been done on 110 feet before the average age of six and one-half years, and that the feet were still not corrected. They say, "Forceful wrenchings had previously been done on many feet. In each instance, the deformity recurred two or more times".

How long will it take us to learn to stop treating club feet by "forceful wrenchings" and by the use of the eight different cutting operations which were used on this group? I am almost persuaded that there is still a need to continue the teaching of conservatism in the treatment of club feet.

The authors say, "This operation was chosen, rather than arthrodesis, transtarsal wedge osteotomy, or other bone-cutting operations".

They say that in addition to anterior tibial transplantation, most patients had wedged casts for two or three months postoperatively, and that these two procedures gave very satisfactory results in 83 per cent. of the series. I wonder why they are so reluctant to give the less spectacular eight to twelve weeks of casts and wedgings some credit for their good results.

Twenty-seven of these 110 feet needed some additional operations after the tendon transplantation, and they have still a long growth period ahead of them.

About fifteen years ago, Dr. John Royal Moore of Philadelphia told me about a small series of patients with congenital club-foot in which he had transplanted the anterior tibial tendon to the lateral border of the foot. He found that it threw the foot out of balance, as time went on, and that he had to put it back in place in a large proportion of cases. He abandoned the operation without publishing the results.

In the short period of five years, Dr. Garceau and Dr. Manning have had to put two back, and they say a third child needs it. Many more may need it before the growth period has been completed.

My suggestion is that we all spend time and thought on how to improve our plaster technique. We will then have the satisfaction of knowing that we have done no harm to the foot. We will see club-footed children go into life with more flexible and useful feet, and with fewer adhesions and scars.

Dr. Charles W. Peabody, Detroit, Michigan: Dr. Garceau has made an excellent presentation of his treatment in this paper, and I am sufficiently acquainted with his work and character to give major consideration to any observations and conclusions he makes. I have also seen the results in some of his cases.

I appreciate his calling upon me to participate in the discussion, and I believe I know his reason. Some fifteen or more years ago, I presented, at an Association Meeting, a paper which involved a study of congenital metatarsus varus. This paper included an operative observation of an instance of this deformity where the anterior tibial tendon lacked any normal bony insertion.

Subsequently, I found the same anomaly in a recurrent club foot, which remained corrected after such tendon transposition. So, I believe the possibility of such an anomaly must be considered in the treatment of either type of congenital foot deformity.

Furthermore, I have long stressed not only the influence of muscle imbalance in producing foot deformities, but also the necessity of balanced redistribution, no matter what else is done.

I have also held to the theory that talipes equinovarus results from a prenatal muscle imbalance, due to an imperfect development of pronator and extensor function. I am convinced that often a permanent residual insufficiency prevails in the three peronei, and that, when this can be demonstrated in the recurrent cases, transposition of the anterior tibial tendon is indicated. However, I believe it is always difficult and usually unnecessary to make the shift as far out as Dr. Garceau does; for if the skeletal deformity is adequately corrected, mid-foot transposition is enough and reversed imbalance is more likely to be avoided.

Now, in case Dr. Garceau does not do so in closing, I want to further stress the absolute necessity for complete overcorrection and maintenance of it until functional recovery of the evertors, with total muscle balance, has had opportunity to occur. With any persistence at all of either supination or of forefoot varus, the different fulcrum points in the foot are so far off their dead center that one set of muscles works at an enhanced advantage and the other at a major mechanical disadvantage.

Dr. Eben W. Fiske, Pittsburgh, Pennsylvania: Over thirty years ago, I came out with a very definite stand on the conservative treatment of club-foot. It was nothing new then; the doctors all knew it, but for some reason they had constantly forgotten it. In the Children's Hospital at Boston, we had a series of early cases in which operation was performed. I had the opportunity to watch what happened to these patients, as compared to those who were treated conservatively. We developed a technique of conservative treatment with no attempt at operative treatment and without any cutting, any anaesthetic, or any stretching. Not only were the results better, but they remained better. To me the key to the whole matter was the absence of trauma. It is not a matter of re-establishing bones and joints, it is a question of not traumatizing the bones or joint surfaces, or the vessels and nerves. I still believe that one of the important features in the successful treatment of club-foot is that we should carefully treat these cases without any force or trauma. When we do that, we will have preserved all the tissues in the foot, and we will be able to restore them to normal, and have the functional result that we should have.

I am interested in Dr. Kite's method, but I have had little experience with it, because I like my own. I feel that, if we mold these feet without trauma and do it often enough, we will get a result. As Dr. Kite stressed, the foot itself must be corrected by abduction and eversion first. Complete overcorrection will result in a foot that will function properly. The muscle balance will correct itself, and we will have no worry about tendon transplantation.

Dr. George J. Garceau, Indianapolis, Indiana (closing): I wonder what Dr. Kite does with the 10 per cent. of cases which he reports unsatisfactory? This operation was performed on 6.7 per cent. in our series of 1,275 patients. In discussing bone-cutting operations for recurrent club feet, Dr. Kite says, "If the feet should relapse, the same operation can be done again, removing a little more bone where necessary, and a successful correction obtained". We have done anterior tendon transposition rather than a bone-cutting operation. We have had to restore the anterior tibial tendon to its former natural insertion, but I can see no objection to this. It is a small price for obtaining a good weight-bearing foot.

This operation is resorted to only when recurrence of the deformity cannot be prevented and the indication of muscle imbalance is present.

INTERTROCHANTERIC FRACTURES OF THE FEMUR

A Survey of Treatment in Traction and by Internal Fixation*

BY MATHER CLEVELAND, M.D., DAVID M. BOSWORTH, M.D., AND FREDERICK R. THOMPSON, M.D., NEW YORK, N. Y.

From the Orthopaedic Service of St. Luke's Hospital, New York City

This survey of 133 consecutive cases of intertrochanteric fracture of the femur, from the Orthopaedic Service of St. Luke's Hospital, includes follow-up studies in 94 per cent. of the cases. In only seven patients, all from the group treated conservatively, is the final outcome not known. The final outcome of all patients treated by internal fixation is known, and recently they have been examined by the authors for the purposes of this study. The series consists of (1) a group of thirty-eight cases treated mainly by traction, and (2) a group of ninety-five consecutive cases treated by internal fixation. The period of study extends from August 1938 until January 1947. During the first three years, treatment was by traction, usually of the Russell type, although two cases were treated with well-leg traction and one with skeletal traction through the lower end of the femur. This survey is an endeavor to compare the results among those patients treated by internal fixation with the results among those upon whom traction was employed.

AGE AND SEX

These patients were elderly, with average ages from twelve to fifteen years higher than those previously reported with intracapsular fractures.[1] Patients treated with traction had an average age of seventy-eight years, while those treated with nail fixation had an average age of seventy-five years. Over half the patients in each group were in the eighth and ninth decades of life. They had, therefore, but a few years of life expectancy. Those who survived for several years were usually in the younger age group,—the seventh decade or younger (Table I).

The sex incidence in the two groups shows that 90 per cent. were women. The preponderance of female patients is probably explained by their less rugged bony structure, and usually more pronounced atrophic osseous changes. Actuarial statistics from a large insurance company show that, at the age of seventy-five, there are 108.9 females alive to every 100 males. In other words, only about 9 per cent. more women are alive at that age than men. Our ratio of fractures in women as compared with those in men, however, was 9 to 1. This should be compared with another group reported from this Hospital [1, 2], with fractures of the neck of the femur, in which the ratio of women to men was 4 to 1. There must, therefore, be some definite cause for the higher female incidence, such as that just mentioned.

RACE

In this series of patients, there has been no instance of a negro patient with a trochanteric fracture. This is so despite the fact that St. Luke's Hospital lies close to the Harlem district of New York City. Such cases do occur, since they are encountered occasionally by one of the authors in another city institution, but apparently they are not so common among aged negroes as among aged whites. The more rugged skeletal frame of the negro may be the reason.

* Read at the Annual Meeting of The American Academy of Orthopaedic Surgeons, Chicago, Illinois, January 28, 1947.

FIG. 1-B

FIG. 1-A

Fig. 1-A: Use of a Smith-Petersen nail in the simplest type of fracture may secure a good result, but it is apt to prove ineffective.
Fig. 1-B: The use of multiple threaded wire is inefficient, and complicates the operative procedure.

FIG. 1-C

Fig. 1-C: The use of multiple screws secures fixation, but generally fails to prevent coxa vara from developing. The screws may become loosened and wander.

FIG. 1-D

Fig. 1-D: The Thornton nail, when placed, is mechanically weak at the juncture. Such apparatus is more liable to breakage, bending, or loosening of the bolt than is a cast one-piece nail. The methods illustrated in Figs. 1-A, 1-B, and 1-C were tried, but all were discarded.

LOCATION OF FRACTURE

The authors were prepared to find a preponderance of these lesions on the left side. This was revealed, the frequency being 2 to 1. Of the ninety-five fractures which were nailed, seventy-eight were pertrochanteric; and as a rule they were comminuted. Five were subtrochanteric, really involving only the upper femoral shaft. Three were paratrochanteric, involving the base of the neck, and usually were not comminuted. Of the combined fractures, four involved the base of the neck and the trochanter; three involved the trochanter and the shaft; and two were those fractures usually so difficult to treat,—the combined transcervical and trochanteric fracture.

TABLE I

GROUPING OF PATIENTS IN RELATION TO FORM OF TREATMENT

Age		Method of Treatment	
Decade	Years	Traction	Jewett Nail
Fifth	41 to 50	0	3
Sixth	51 to 60	3	6
Seventh	61 to 70	5	16
Eighth	71 to 80	8	43
Ninth	81 to 90	20	21
Tenth	91 to 100	2	5
Eleventh	101 to 110	0	1
Totals		38	95

ASSOCIATED DISEASES OR PATHOLOGICAL CONDITIONS

These elderly people represented a veritable museum of pathological changes, antedating their trauma. The most serious and most common associated lesions were cardiac, diabetic, and senile mental changes. A number of the patients had not walked prior to the fracture, and of course they never walked thereafter. Comfort and simplicity of treatment plus extension of the expected longevity were all that could be provided. Renal lesions, severe crippling arthritis, syphilis, carcinoma, hemiplegia, and the many afflictions of the aged were seen. Rarely was a "good operative risk", in the general surgical sense, encountered. Despite this, they withstood operative trauma, when the procedure was rapid and attended with careful supportive treatment and anaesthesia, as will be seen.

TYPE OF INJURY PRODUCING THE FRACTURE

The causative injury was often trivial,—a simple fall, tripping over a rug, arising from a chair, or some slight misstep. Some individuals were injured by direct violence. Many, we believe, fractured the bone by a twist, dissolution of continuity occurring before the patient fell to the ground. This mechanism is similar to that causing an intracapsular lesion. The main factor contributing to the injury lies in the elderly person's inherent instability while erect, and in his slow reflex proprioceptive response.

REASONS FOR ATTEMPTING INTERNAL FIXATION

At St. Luke's Hospital, until 1942, the standard treatment for trochanteric fractures, as has been stated, was usually traction. Although this was thought to be eminently satisfactory, a review of the records of these patients has shown a great many complications in the course of their treatment, which were unappreciated at the time. In spite of excellent

nursing care, pressure sores over the sacrum and buttocks were the rule rather than the exception. Cystitis and bladder complications were frequent. Knees, made stiff from prolonged traction, were difficult to restore to normal. Many patients were left with some residual contracture of the hip or knee. Permanent vascular changes, peroneal-nerve palsies, muscle atrophy, psychoses, prolonged general inanition and debility, and a high mortality were disclosed. In follow-up examinations in the Out-Patient Department, many patients showed a crippling external rotation of the hip, in spite of roentgenographic evidence of apparent reduction of the fracture. Although the patients with badly displaced and comminuted fractures had the worst results, in many of the "simple" cases the outcome was poor. For these reasons, an attempt was made early in 1940 to hold the fracture in good position by some form of internal fixation.

TYPES OF INTERNAL FIXATION

It was found that undisplaced fractures, or those with minimum displacement without extensive comminution, could be held in place successfully with the Smith-Petersen nail (Fig. 1-A). The limb did not have to remain in traction for the long period of time which was necessary without nailing. Straight-nail fixation, however, was applicable to only a few of these undisplaced fractures, and it was apt to fail even there. It was not applicable to the majority of fractures, which were comminuted or displaced. This use of the simple straight nail for trochanteric fractures has been discarded.

Next, threaded pins were used (Fig. 1-B). They, too, were discarded as lacking stability, as unsatisfactory for comminuted fractures, and as unnecessarily complicating the operative procedure.

An attempt was then made to fix the fragments of the comminuted type of fracture in place with several Vitallium screws (Fig. 1-C). This procedure was complicated, needed extensive exposure, and was not successful in preventing coxa vara unless traction was also maintained.

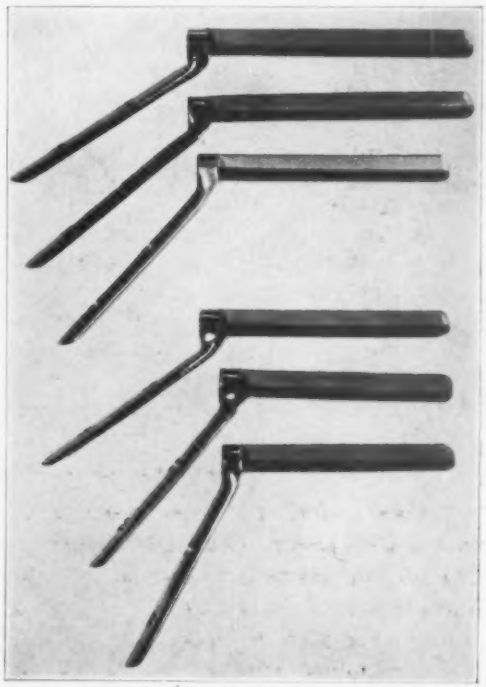

FIG. 2

To handle satisfactorily the various situations encountered, six types of nails are needed. There should be three angles for each nail, and a long and short nail in each angle.

Early in 1942, the Thornton type of combined plate and nail was used (Fig. 1-D). With this appliance, too, although the undisplaced fracture could be held adequately and maintained in proper position, the displaced or comminuted fracture bent into the coxa vara position during subsequent months. This was due to inherent instability at the juncture of the nail and the plate.

The answer to these objections seems to have been found in the angled one-piece nail and plate, described by Jewett in 1941. As the use of this appliance increased, certain situations arose which demanded changes in its structure. The main changes have been as follows: The vertical flange on the deep surface, at the juncture of the plate and the nail, has been removed. This flange caused increased comminution of the trochanteric structure of the femur in several instances as the nail was driven home; and, on several other occasions, increased comminution was due to attempts at cutting a trough for its reception. A passageway for the Kirschner wire, used as a guide, was eliminated. This weakened the

FIG. 3-A

FIG. 3-B

Fig. 3-A: Shows use of the nail in a severely comminuted and displaced fracture. Note reassembling of fragments.
Fig. 3-B: Subtrochanteric fracture (really a high-shaft fracture) maintained in position by use of the nail. No other method of treatment has been as efficient in this type of fracture.

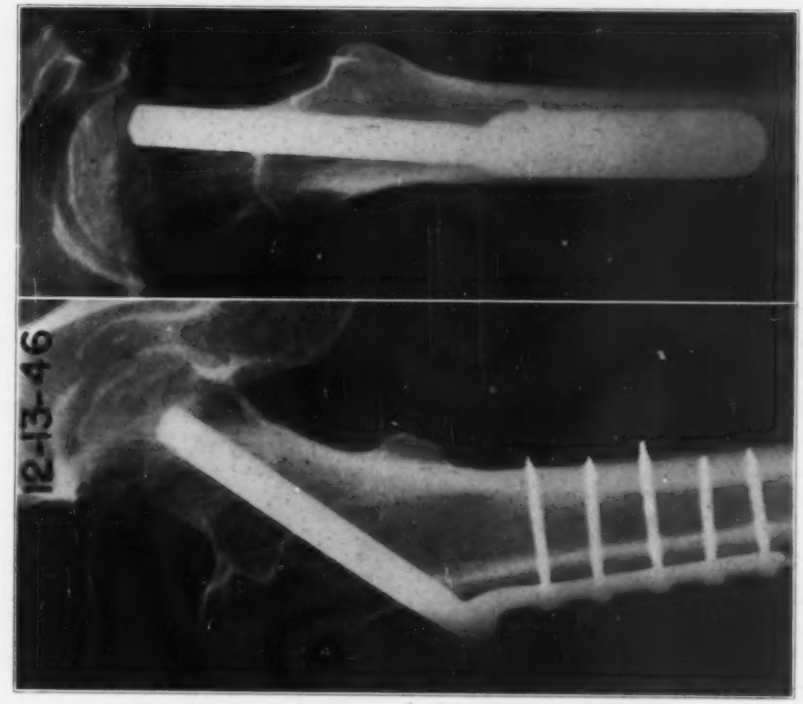

FIG. 3-D

FIG. 3-C

Combined fracture of the trochanter and the intracapsular region of the neck, controlled by an angled nail. Perfect union in both locations resulted.

nail or made it more cumbersome. Use of such a wire merely complicated the operative procedure, and in the authors' hands it did not prove helpful. Reinforcement of the juncture of the nail with the plate was secured by thickening of the plate at this point. The casting of nails with three angles (130 degrees, 140 degrees, and 150 degrees) allowed for close coaptation of the plate to the femoral shaft, regardless of the angle of the neck at the time of reduction and without the necessity of bending the apparatus (Fig. 2). The casting of a nail of each angle in a normal and in a short length obviated overdrive in severely comminuted fractures. The removal of the streamlined head and its replacement by a ledge behind the head of the nail, for application of a hook extractor, facilitated removal when threads in the base of the nail were stripped and a threaded puller could no longer be used.

Such a nail can be used successfully in even the severely displaced and comminuted type of paratrochanteric or intertrochanteric fracture (Fig. 3-A). It has the added advantage of being of great practical use in the difficult subtrochanteric type of fracture, high in the femoral shaft (Fig. 3-B), and in that rare type in which both the neck and the trochanteric region are involved (Figs. 3-C and 3-D). It is possible by open reduction to fit the fractured fragments into satisfactory alignment, and to hold them there by internal fixation. Frequently even the lesser trochanter can be engaged, and the fragments can be held in reduction by the upper screw. If nailing is done properly, with the nail well placed in the head of the femur, coxa vara will not develop unless the nail breaks, bends, or pulls out of the bone. The nail most frequently used has an angle of 130 degrees and is three inches in length; it is made of non-electrolytic material. The authors have not used the blade-plates described by Blount and Moore, although these undoubtedly are effective.

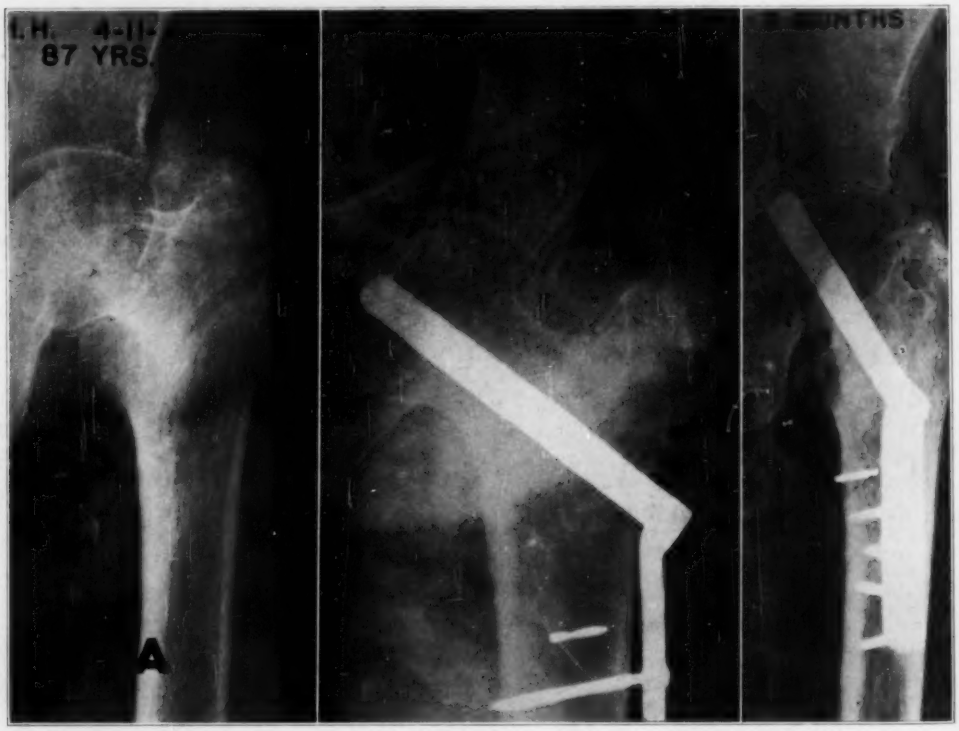

FIG. 4-A

Gradual telescoping of fracture site, without the development of coxa vara, allows protrusion of the nail into the head during healing. This is called "overdrive", although the nail may not have been driven through the head at operation. Such telescoping at the fracture site generally ceased by the end of three months, with the development of union.

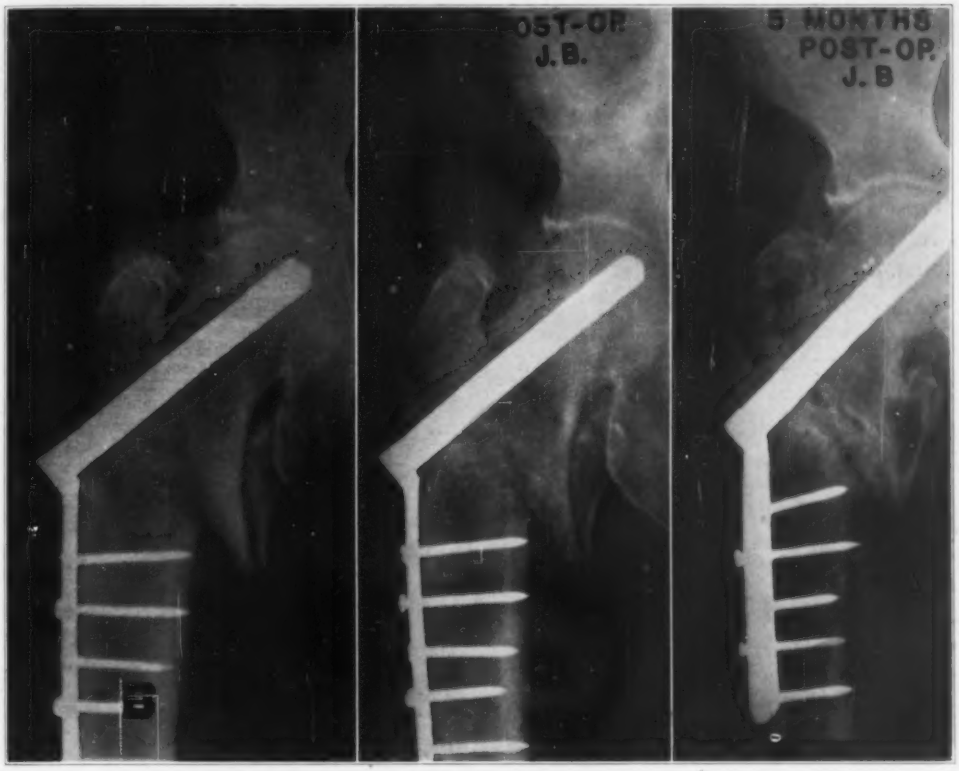

FIG. 4-B

In certain instances, protrusion progressed after three months. No protrusion has been noted in this series after the seventh month, which indicates that solid union does not always occur in these fractures before the seventh month.

ANAESTHESIA

The authors believe that the low immediate mortality rate is due in large measure to the choice of anaesthesia and to the use of a blood transfusion at operation. Preoperative morphine sulphate and hyoscine are given an hour before a minimum dose of avertin. Complete anaesthesia is induced twenty minutes later with a mixture of cyclopropane, nitrous oxide, and oxygen.

OPERATIVE AND ROENTGENOGRAPHIC TECHNIQUE

Both a surgical team and a roentgenographic team who are acquainted with the nailing procedure must be employed for the smooth and rapid handling of such cases. Trochanteric fractures should be handled with gentleness and a minimum of manipulation. Simple trochanteric fractures sometimes become comminuted on the operating table by vigorous manipulation. Light traction, moderately forceful internal rotation, slight hip flexion, and gentle abduction secure the best reduction. The uninvolved hip may be abducted fully to fix the pelvis and to allow for lateral roentgenograms, as necessary. The foot of the table may be dropped to facilitate this manoeuvre. Following standard sterilization and draping, a lateral incision, through all structures to the upper third of the femur, should be made with minimum laceration of muscle tissue. This is of great importance, as will be seen from the two cases in this series in which gas gangrene developed. A skin clip may be placed over the location of the femoral head, as a guide in driving the nail and as a marker for subsequent roentgenograms. After films have been taken to show the reduction, a Jewett nail with the proper angle and of the proper length may be chosen.

The point of entrance of the nail below the trochanteric ridge will depend upon the

nail chosen, and is usually nearer the ridge than in intracapsular fractures (an average of three-quarters of an inch). The femur should be drilled at this point, with a hole sufficiently large to prevent shattering of the cortex when the nail is driven in. In most cases, the trochanter must be lifted forward, as the nail is driven horizontally inward and upward. Fixation of the plate with two screws will then allow trial rotation of the hip. If grating occurs, faulty position of the nail or overdrive is present. In this event, roentgenograms are taken, and the position or length of the nail is corrected, as necessary. If rotation is free in extension and flexion, the remaining screws are placed; roentgenograms are taken; and the wound is closed during their development. Should changes in the nail position be necessary, a few seconds only are required for re-exposure. Much time will usually have been saved.

With many of these hips to nail, the authors have been concerned over the amount of roentgen rays to which the doctors, residents, and nurses are exposed while check-up films are being taken. After experimentation with various types of cones and lead-lined tunnels, two simple methods of protection have been employed. A small lead diaphragm, devised by the Roentgenographic Department, is placed in the tube aperture. The small central hole of the lead diaphragm is fashioned so as to prevent the spread of rays beyond the area of an eight by ten film. When the anteroposterior view is taken, the patient is lying on a tunnel, which allows rapid change of the cassette without moving the patient. There is no danger of the hands of the personnel being exposed to roentgen rays during this episode. Frequently, when the lateral film is taken, however, someone must hold the cassette, so that it is pushed strongly into the side of the patient, just below the ribs and above the crest of the ilium. Wound retractors can be used as hooks over the edge of the sterile-draped cassette, superiorly and laterally. It is held firmly in place against the patient, and the hand is screened by the cassette. The lead lining, in the back of every cassette, prevents the rays from going through. By actual Victoreen test, the hand behind the cassette receives no measurable roentgen rays. For such a view, the roentgen tube is placed at the inner side of the knee of the normal lower extremity, which has been abducted. Usually a lateral postoperative view can be taken with the hip in flexion, which avoids the difficulty of holding the film. With a trained surgical and roentgenographic team, the average operating time may be held to thirty minutes or less.

POSTOPERATIVE CARE

After operation, the patients are placed in light traction to prevent external rotation. This temporary traction during the early postoperative period provides a considerable amount of comfort. It is usually ten days before a toe-to-groin Thomas brace with pelvic band and knee lock can be delivered. Such a brace is used until union is solid, to prevent external rotation. Some of the patients have been allowed up in a chair within a few days after the operation. However, early weight-bearing, even with the brace, is harmful. It may cause the nail to break, bend, or even protrude through the femoral head. In the postoperative roentgenograms, it has been noticed that the nail protrudes farther into the proximal head fragment, chiefly during the first three months, before union has occurred (Fig. 4-A). In some few cases, further protrusion has been noted after the third month (Fig. 4-B). No protrusion has been noted after the seventh month. It is probable that too active weight-bearing can encourage this protrusion. In the majority of the patients, some absorption of bone at the fracture site took place, with gradual approach of the nail tip towards the articular margin. Early movement of the patient, without actual weight-bearing, is beneficial. The authors do not feel the need for early complete mobilization of these patients, advocated by others. Postoperative pneumonia is not so greatly feared since the advent of penicillin. Pulmonary embolus is still feared, although only two cases have been noted in this series.

Close observation and general care pay high dividends in results in these aged people.

Feeding the patients is a difficult problem, and in itself requires special nursing care. A high-protein intake should be insisted upon. Fluids are supplied by infusion, if necessary, during convalescence. Vitamin-B therapy is almost routine. Close attention is paid to the skin at the point of traction, and the back is inspected daily. Incontinence is treated immediately by indwelling catheters; frequent changes of bed linen are essential. Prompt cessation of sedation is demanded. The importance of cardiac investigation, consultation, and medication, when necessary, should always be borne in mind. We should remain continuously aware of the fact that these patients are old, afflicted with many debilitating factors aside from their fractures, and have been injured badly.

COMPLICATIONS

1. Infections

Four cases of infection occurred in the patients who had been operated upon. In two patients, an infected hematoma developed. One of these was evacuated spontaneously, and healed promptly. The other was still draining, but without general reaction, when the patient died of inanition on the thirty-fifth day after operation. Gas gangrene, resulting in death, developed in two men. Autopsies were performed on both. Both had two or more lines of incision through the deep muscle tissues lateral to the upper third of the femur, which destroyed the blood supply to a sizable portion of muscle tissue. One of these patients was 103 years of age. It is the authors' feeling that, in these aged patients, with vitality of muscle tissue at a minimum, further destruction of the blood supply by an incision (especially if accompanied by laceration of the deep tissues) may promote much

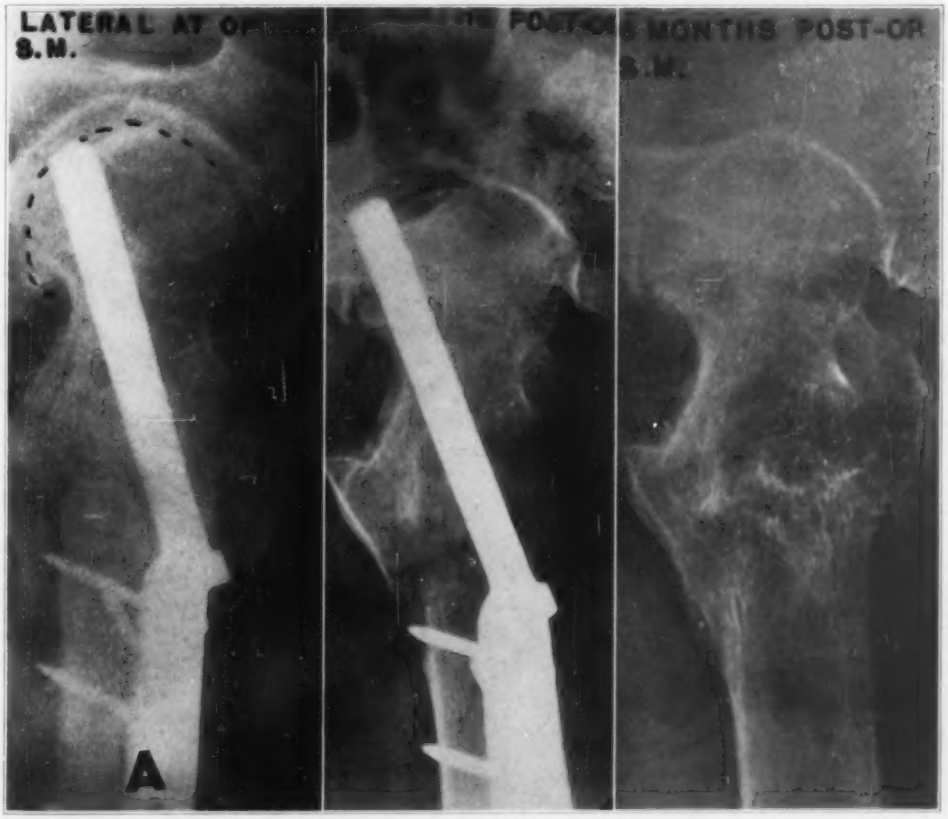

FIG. 5-A

Protrusion or overdrive gradually developed after operation. Removal of the nail following union relieved symptoms routinely.

FIG. 5-B

FIG. 5-C

Fig. 5-B: Disruption of nail through the side of an atrophic head and neck occurred on the second day after operation. This nail was withdrawn and a new one was inserted; the roentgenogram at the right shows the appearance of the head three months later.

Fig. 5-C: Early weight-bearing, against advice, caused these screws to pull out of the shaft of the femur four months after operation. This required subsequent surgery.

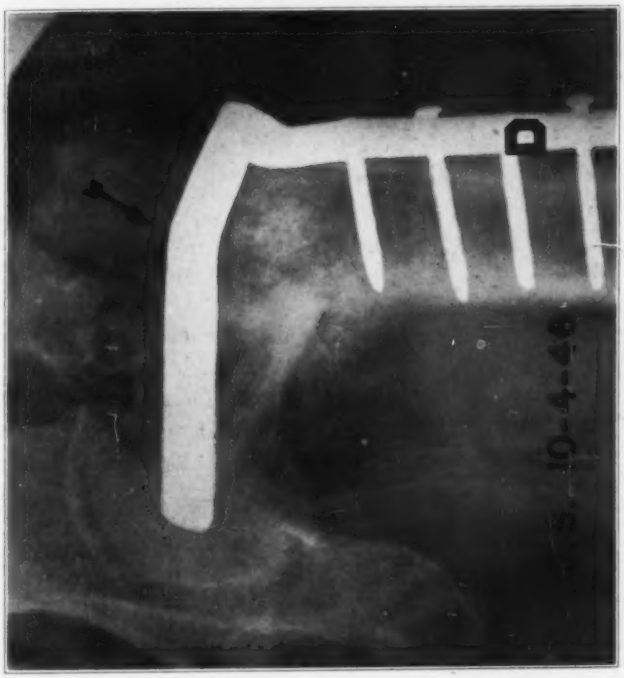

FIG. 5-E

Fig. 5-D: Fracture of the nail, either in the plate or in the three-flanged portion. This occurred twice in the flange and once in the nail. Two nails were replaced and one was removed. In all three patients, union was satisfactory.

Fig. 5-E: Bending of the nail occurred once. Removal of nail, with application of traction, resulted in union, although with mild coxa vara.

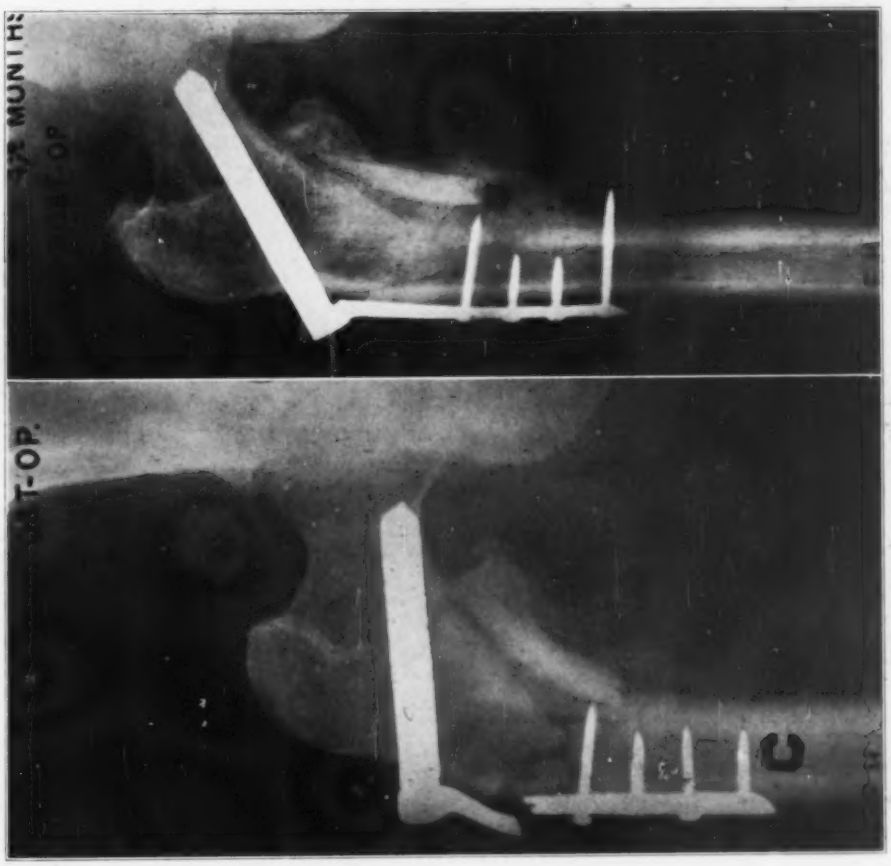

FIG. 5-D

more necrosis than would occur in patients in a younger age group. As was found in severe battle wounds (to which these wounds are comparable), such conditions are extremely favorable to the development of gas-producing anaerobes.

2. Pulmonary Embolus

One would expect a considerable incidence of pulmonary embolus in such a series after operation, but only two instances of this condition were found. Both of these patients died; on one patient, an autopsy was performed. The embolus causing this fatality arose from the deep veins of the uninjured leg, there being no sign of thrombosis of the veins on the injured side. The patient's treatment had been entirely neglected for ten days prior to her entry to the Hospital. Apparently thrombosis had occurred, unsuspected by us. Manipulation, incident to operative reduction, cannot be disregarded as a factor in the fatal termination of this case. We believe that the fatal embolism in the second case on the thirteenth postoperative day is not an operative mortality. There was no clear-cut instance of embolism among the patients who died, following treatment by traction.

3. Pneumonia

Postoperative pneumonia occurred in two patients (2.1 per cent.), and was treated successfully without fatality.

4. Overdrive

The most common complication in this series has been that resulting from driving the nail too close to the dome of the femoral head (Fig. 4-A). The nail need not have been driven through the head at the time of operation to have made this complication possible. The authors had not realized that there would be much absorption at the fracture site in the healing of these fractures. These patients left the Hospital at a much earlier date than those treated by traction, and at the time of their discharge check-up roentgenograms showed a well-driven nail, close to the cortex of the femoral head, which we judged to be an excellent supporting structure. It was only when the patients were called back for follow-up that it was discovered in their roentgenograms that bone had been absorbed at the site of fracture, with telescoping. This caused the nail to protrude into the acetabulum, since its base was affixed firmly to the shaft of the femur through the attached plate (Fig. 4-B). Strangely enough, not many of the patients had complained of a grating sensation on movement of the joint, nor had they complained of much pain. The roentgenogram disclosed this situation, rather than the statement of the patient. In certain other patients, several attempts were necessary at operation to place the nail satisfactorily in the femoral neck. In a few of these, after several attempts, the operation had to be terminated before the nail had been placed satisfactorily, because of the poor condition of the patient. Although the position of the nail was not perfect, it was felt that it did not extend beyond the cortex of the femoral head, and that healing would be uneventful. During subsequent months, these nails continued to protrude through the head into the acetabulum. Their removal has been simple and without operative complication. Traumatic arthritis, where such nails have cut notches in the acetabular roof, has not caused these patients severely annoying symptoms. Overdrive is most apt to occur in the severely comminuted intertrochanteric fracture and the trochanteric fracture which is more nearly through the base of the neck. It has been noted, however, that, although the fracture line often becomes absorbed and the neck telescopes down on the nail, the angle of the head and neck fragments relative to the shaft remains the same, and does not bend into a coxa vara position. In all, nine nails have been removed for various reasons. In four situations, removal of the nail-plate was considered to be justified (Figs. 5-A, 5-B, 5-C, 5-D, and 5-E). The first situation, and one which occurred most frequently, has been protrusion of the nail; second, disruption of the nail from its contact with the head or the shaft of the femur;

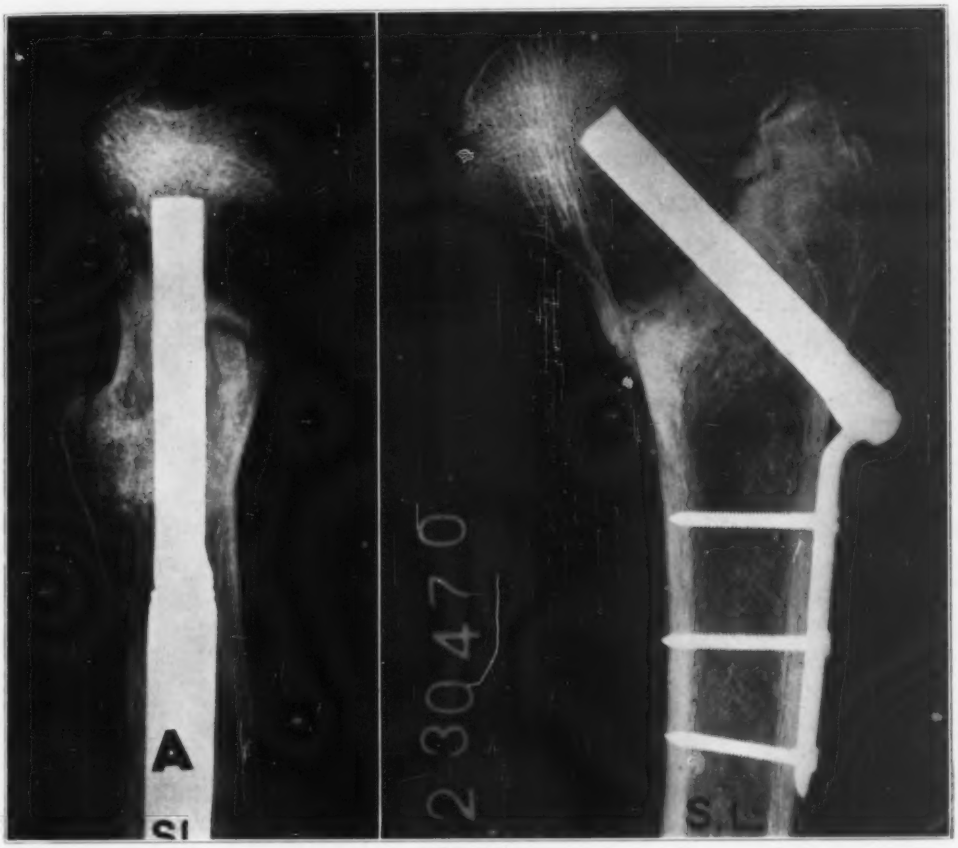

FIG. 6-A

Roentgenogram of autopsy specimen, with nail in place, shows internal structure of bone. Most favorable site for the point of the nail to be imbedded is the lower portion of the neck and head. Nail shown was placed too high in the neck; but despite this, it had held and union was progressing.

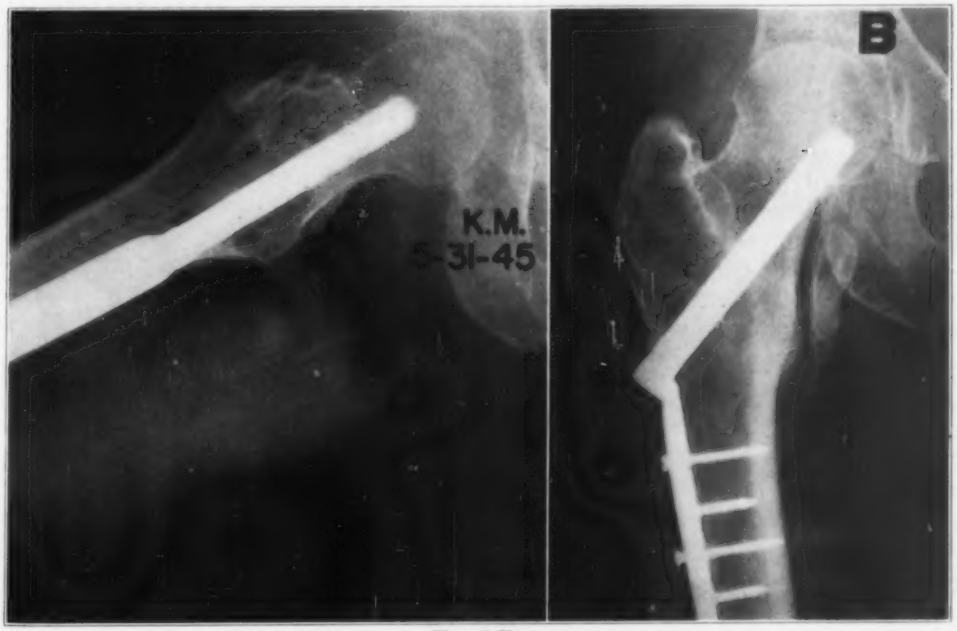

FIG. 6-B

Example of perfect nailing, with nail placed low in head and centered in lateral view. Fracture of lesser trochanter was disregarded; no clinical objective or subjective symptoms present related to it.

third, the necessity for replacement of a bent or broken nail; and fourth, continuous discomfort over the plate distal to the trochanteric region. Nail protrusion occurred chiefly among the earlier patients, before the authors were aware of the possibility of this situation. It has rarely happened in the later cases, since the proper length and angle of the nail have been insisted upon.

5. Nail Breakage, Bending, or Disruption

In three instances, the nail became fractured from early weight-bearing (Fig. 5-D). In two of these, the broken nail was immediately replaced by a new one, with ultimate firm union. The third instance occurred when a patient walked without support the second day after operation. Wide separation of the fragments resulted. Traction was employed, and union, although delayed, eventually took place with marked external rotation of the lower extremity. In one instance the nail bent through the three-flanged portion. This nail was extracted, and the patient was put in traction; satisfactory union resulted, but with some coxa vara. In four other instances the nail tore out of the bone in which it had been inserted (Fig. 5-B). In two of these, the nail ripped out of the side of a decalcified femoral neck and head. In one a new nail was placed, but protrusion gradually took place as union occurred, and the nail will have to be removed. In the other instance, a severely deformed arthritic old lady, union occurred without pain but with considerable deformity. This patient had not been ambulatory before operation; and, since she is without pain, no attempt has been made to remove the nail-plate. In two instances the screws pulled out of the femoral shaft (Fig. 5-C). In the first, the nail was replaced, and the patient obtained an excellent result. The second patient had the nail removed, and a subtrochanteric femoral osteotomy was performed to correct the external-rotation deformity which occurred; good weight-bearing and ambulation were obtained, although with marked restriction of hip motion.

Roentgenograms of autopsy specimens from patients whose fractures had been reduced and repaired by nail fixation, confirmed by anatomical studies, show that the nail should be implanted in the inferior portion of the femoral head and neck, and that there it will be imbedded in the densest portion of the calcar femorale (Fig. 6-A). The anteroposterior roentgenogram should show the nail implanted in the lower portion of the head, and in the lateral view it should be centered (Fig. 6-B). It should not approach closer than one centimeter to the articular surface of the head, for fear of gradual protrusion. Screws fastening the plate to the femoral shaft should perforate and grasp both the proximal and the distal cortices. Where convenient, the lesser trochanter may be engaged by one of the screws, although failure to so secure it does not vitiate a good functional result (Fig. 3-A).

6. Subtrochanteric Fracture

Production of a subtrochanteric fracture at operation, during an attempt to nail an intertrochanteric fracture, has occurred on five occasions (Figs. 5-B and 5-C). It has not been a very annoying complication, since the nail supports both fractures satisfactorily. No untoward results have been seen from this operative accident.

7. Non-Union and Aseptic Necrosis

No instance of non-union of a trochanteric fracture has occurred among the survivors. There have been two cases of delayed union. The first occurred in a patient whose screws pulled out of the femoral shaft. The second patient walked on the eighth day after operation, against advice, and bent the nail so that the neck became angulated 40 degrees into a coxa vara position. No case of generalized aseptic necrosis of the femoral head has occurred from the use of these nails. A few localized areas of necrosis near the nail tips have occurred in patients when the nail was lying high in the head of the femur, and these have been associated with traumatic arthritic changes.

8. Mortality (during the Hospital Stay)

Of thirty-eight patients treated conservatively, mainly with traction, thirteen died during their hospital stay,—a mortality of 34 per cent. On the other hand, among ninety-five patients treated with internal fixation, there were only twelve deaths, a mortality rate of 12.6 per cent. The hospital mortality rate following conservative treatment, in our hands, was much larger than that resulting from surgical fixation. By a mortality rate of 12.6 per cent. in the nailed group is meant that these twelve patients died before leaving the hospital. We feel that the operation was responsible for but four of these deaths. Two elderly women died the day after operation,—one of shock (traumatic and operative) and one of pulmonary embolism. Two men died of gas gangrene as a result of operation. The eight remaining deaths (seven due to cardiac failure and one to embolus) took place from the fifth to the twenty-eighth day after operation. We feel certain that these deaths are not the result of operative trauma, since an analysis of the patients treated in traction shows that 70 per cent. of the hospital mortalities occurred before the twenty-sixth day.

9. Senile Psychoses

The development of severe and permanent senile psychosis is considered an extremely serious complication. Not only are these patients divorced from the rest of their active lives, but they demand continuous and expensive care, and continue an existence of considerable debasement and suffering. Of the thirty-eight patients treated conservatively, four (11 per cent.) were transferred to mental institutions, because of the development or aggravation of senile psychoses and dementia. Of the ninety-five patients operated upon, only two (2.1 per cent.) were transferred to mental institutions. This decrease in the incidence of severe psychoses among the group operated upon is due in part to an earlier return to active status, and in part to extensive intramuscular vitamin therapy.

10. Decubitus Ulcers

In only eight patients of the series having operations (8.4 per cent.) did pressure sores of any nature develop.

11. Disabling Deformities of the Hip and Knee

There were no knee deformities incident to the nailing procedure. The final range of motion of the hip was improved over that obtained in patients treated with traction.

12. Incontinence

Although the occurrence of incontinence was as common among the patients in traction as in those treated with fixation, the latter were immeasurably easier to handle.

SURVIVAL RATE

Due to the advanced age of the patients who sustain intertrochanteric fracture, it is evident that not many patients will survive for more than a few years, regardless of trauma or operation. A review of the cases treated by traction shows that only 32 per cent. were living one year from the date of fracture. By the end of the second year, 29 per cent. were alive; at the end of four years, only 13 per cent. were alive. In comparing the group treated by traction with those treated by internal fixation, we note a decided contrast. In the group treated by internal fixation, 72 per cent. were living one year from the date of the fracture, 38 per cent. survived two years, and even 30 per cent. of those in whom nailing was carried out four years ago have survived.

LENGTH OF HOSPITAL STAY AND EXPENSE

The average patient with an intertrochanteric fracture is an unwelcome guest in the hospital ward for a prolonged stay. In those cases treated in traction, the average number

of hospital days was ninety-eight, or fourteen weeks. The patients treated by internal fixation remained in the hospital an average of fifty-seven days, or a little over eight weeks. Even the eight weeks' stay of the patients who were operated upon was a kindness rather than a necessity. This method of treatment almost halves the length of time the patient needs to remain in the hospital. Many patients are able to pay but a small part of their hospital expense. The major share of the cost of treatment must be borne by hospital endowment or by other community resources. This reduces the availability of such resources for other needy cases. Were expense alone to be considered, this might not prove important; but, when viewed in the light of other foregoing statistics, it certainly becomes so.

SELECTION OF CASES

In the past two years the authors have refused to operate upon two patients. One of them lived eight days, and the other twelve days, in traction. The responsibility for not operating upon these elderly patients is serious. These two clearly had sufficient vitality to have withstood the operative procedure. Perhaps had we nailed their fractures, they might have lived. Often we felt that the operation was merely the means of keeping the patient comfortable during the terminal stage, only to find that the patient lived after internal fixation. This is much the same experience as that found in the early days of nailing a fracture of the neck of the femur. The authors have been surprised by the number of patients who have benefited by surgical fixation, even when past experience had indicated that they would die in traction. We now operate upon and nail all intertrochanteric fractures.

SUMMARY

1. Internal fixation reduced the hospital mortality to 12.6 per cent., as compared to 34 per cent. after treatment in traction.

2. Severe senile mental deterioration occurred in 2.1 per cent. of the cases following internal fixation, as compared with an incidence of 11 per cent. in the group treated by traction.

3. The survival rate at the end of four years among the patients operated upon was 17 per cent. higher than in the group upon which operation had not been performed.

4. All complications were reduced sharply in those patients submitted to internal fixation.

5. Although union of the fracture took place in all survivors, the functional result in those treated by internal fixation was vastly improved.

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DISCUSSION

Dr. Rex L. Diveley, Kansas City, Missouri: I am very happy to comment briefly on this excellent study. This is the type of fracture in which it makes very little difference what type of treatment you are accustomed to using; all of these fractures usually heal, but infrequently the results obtained are very poor. A year and a half ago Dr. Cleveland told us that he was carrying on this study, and we informed him that we would carry on a similar study at Kansas City General Hospital. The only difference in our study has been that we are using a Moore blade-plate, and feel that we get less fragmentation with a plate than with a three-flanged nail.

Over a three-year period we have studied 120 consecutive cases, and we have had a mortality in that series of 32.2 per cent. as compared with 36 per cent. in the authors' series. The youngest patient was twenty-seven years of age and the oldest was ninety-four, with an average of seventy-two years. Fifty-six were fe-

males and sixty-four were males. One group was treated conservatively and another was treated by open reduction, for comparison. The conservative treatment consisted of traction, well-leg traction, splints, and, in the largest series, abduction casts. In the series treated conservatively, we obtained good results in 34 per cent., satisfactory results in 43 per cent., and poor results in 23 per cent. In the series treated by open reduction (we have been able to follow only nineteen for a sufficient length of time to know the results), we have obtained 63 per cent. good results and 32 per cent. satisfactory results; there were only 4 per cent. that we termed poor. These results would seem to be far better than those obtained by the conservative method of treatment. Therefore, we highly endorse this method of treatment of intertrochanteric fractures.

DR. PAUL L. NORTON, BOSTON, MASSACHUSETTS: The authors are to be congratulated for their forthright and comprehensive analysis of this series of 133 cases of intertrochanteric fractures with complications. This report is both timely and encouraging. In the past, the intertrochanteric fracture has had a high nuisance value, because it was felt that the fracture would heal regardless of the method of treatment and, therefore, it was primarily a nursing problem.

Analyses of end results have demonstrated that we are dealing with a very serious injury, both as regards the fracture and, more particularly, the life of the patient. This is a fracture of the aged. Of our series of 258 cases, 85 per cent. were over sixty years of age.

Proper treatment must include not only adequate reduction and fixation of the fracture, but also prompt and efficient preparation of the patient. It calls for close cooperation with the internist and the anaesthetist. It calls for the use of transfusions and vitamin therapy in the badly debilitated patient.

The problem of after-care is greatly simplified by the use of adequate internal fixation. The clinical judgment of the surgeon may be taxed severely in evaluating these cases. Should he operate or treat by traction? If operation is decided upon, should it be done as an emergency, or should a "cooling-off" period be permitted, so that supportive measures may be instituted to help the patient through the operation? How long should one wait?

We have had one bolt pull out of a combination Thornton plate and Smith-Petersen nail, and one plate which broke. Overdriving of the nail has not been a factor in our cases. We have been taught to try for a low position of the nail, whenever feasible. If the trochanteric block is intact, the nail alone is usually employed. If comminution is present or if the bone is very atrophic, a plate is used in addition.

There were only two cases of psychosis severe enough to require commitment. Toxic psychoses occurred infrequently.

Thrombophlebitis was a troublesome complication, and five deaths among our cases were ascribed to pulmonary embolism.

Pneumonia, cardiorenal disease, and uraemia were among the causes of death in this series. There were five cases of severe sepsis, either in wounds or in decubitus ulcers. Adhesive dermatitis was an annoying complication.

The end-result studies were as follows:

	No. of Cases	*Deaths*
1923 to 1940	158	41 (26 per cent.)
1941 to 1946	100	33 (33 per cent.)

The over-all mortality was 29 per cent.

In the earlier group of 158 cases, the following treatment was used:

Traction	98 cases
Plaster spicas	32 cases
Operation	5 cases
Bed rest	16 cases
Miscellaneous methods	7 cases

The second group of 100 cases (from 1941 to 1946) were treated as follows:

Traction (2 cases with spicas) . . . . . 49 cases with 19 deaths (39 per cent. mortality)
Operation (internal fixation) . . . . . 51 cases with 13 deaths (25 per cent. mortality)

The outcome in any given case will be determined in large measure by (1) the severity of the fracture, (2) the age and general condition of the patient, (3) the speed and finesse with which the fracture is reduced and maintained, and (4) the adequacy of the postoperative nursing care.

DR. DAVID BOSWORTH, NEW YORK, N. Y.: The nailing of these fractures is more difficult than the nailing of simple fractures of the neck. It is a hard job, and should be approached with care. Do not forget that there is a greater hospital mortality among the patients not operated upon, as well as a higher incidence of senility. The conversion of a patient with an intertrochanteric fracture from a tremendously depressed person to one who is comfortable is a spectacular thing. Open fixation is well worth while, and we use it always.

(*Continued on page 1082*)

INTRAMEDULLARY ONLAY GRAFTS FOR DEFECTS RESULTING FROM SHATTERING FRACTURES *

BY LIEUTENANT COLONEL FRANK G. MURPHY

Medical Corps, Army of the United States

Intramedullary bone grafts have been used on occasions since bone-grafting operations first were performed. Current surgical treatises do not recommend their use, nor are they generally advocated by orthopaedic surgeons. Watson-Jones stated that intramedullary grafting is far less satisfactory than inlay or onlay grafting, and Armstrong has written that "the introduction of a hard cortical plug into the medullary cavity seriously diminishes the blood supply to the bone-ends, and often produces non-union." Boyd reported several cases in which he used an intramedullary fibular graft in cancellous bone with success. Küntscher, in 1940, and more recently Soeur, described the intramedullary fixation of fractures with metal rods. They stated that the normal physiological osteogenesis was not disturbed materially.

Because of the extensive destruction which occurs in long bones as a result of the high-velocity projectiles used in modern warfare, unusual surgical complications have been encountered. A considerable number of these bone injuries included gap defects; these were complete in some, while in others partial bridging by a thin strip of bone, connecting the main fragments, resulted. Metal fragments remained in many patients after early healing.

In a considerable number of cases, massive onlay grafts were not applicable or even feasible, because of comminution and loss of much cortical-bone substance. Here it was found possible to force a graft along the medullary canal, well into the cancellous bone of the end, where it was held fast. The protruding portion of the graft could then be approximated to the shaft of the other fragment, where it could be fastened securely with screws. In the first few cases this procedure was carried out more as an expedient than by design. It was not very difficult to perform, and it fulfilled the requirements for the proper implantation and application of a bone graft.

The indications for combined intramedullary and onlay grafts are (1) ununited fractures near the joints; (2) gap defects in the shafts of the long bones; (3) non-union in which the resultant atrophic cortices are of insufficient hardness to anchor retaining screws; and (4) partial gaps which are bridged by a thin fragment of cortex.

The immediate objectives which are planned are as follows: (1) bridging of the fracture defect; (2) maximum coaptation of the graft to the fragments; (3) moderate stability without the use of additional foreign material; and (4) the avoidance of the hazard of fracture of the graft by placement of screws distant from the fracture site.

PRELIMINARY TREATMENT

All infected tissue, sequestra, accessible metal, and other foreign material are removed. All manifestations of infection should have subsided, and the sinuses should have remained closed, for a period of at least six weeks prior to operation. Long months of delay are no longer necessary before a definitive surgical procedure is begun. Split-thickness skin grafts may be used to hurry the closure of a large clean wound. After the wounds have healed, soft-tissue defects are properly repaired by appropriate plastic procedures.

OPERATIVE TECHNIQUE

The exposure should be thorough, preferably by incisions through healthy tissue rather than through scar tissue. The fracture fragments should be exposed adequately,

* Originally prepared for the monthly Staff Meeting of Battey General Hospital, Rome, Georgia, December 4, 1945. Presented before the Chicago Orthopaedic Society, April 12, 1946.

FIG. 2

FIG. 1

Fig. 1: This patient was injured January 19, 1945; operation was performed on the humerus August 21, 1945. Roentgenograms, taken March 12, 1946, show fracture of the graft. Another graft will be required.

Fig. 2: Injury was received December 4, 1944; humerus was operated upon June 4, 1945. Fracture of the graft occurred on September 30, 1945. Roentgenograms, taken March 12, 1946, show union of fracture of graft. At present, strength is fairly good.

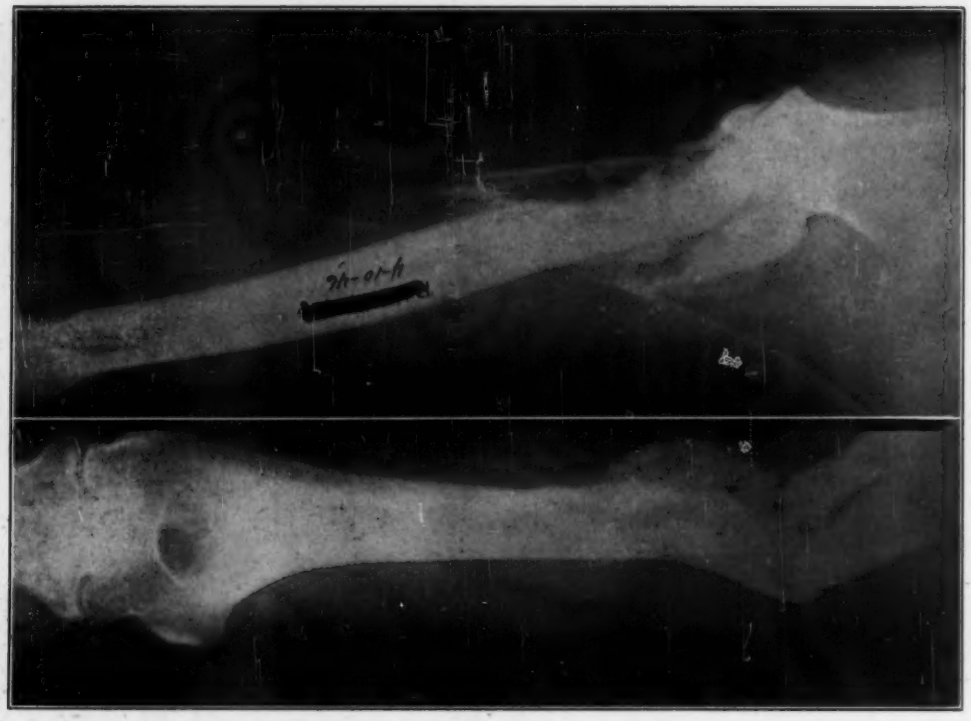

FIG. 3

Patient was injured March 8, 1945; operation on humerus was performed November 10, 1945. Roentgenograms, taken on April 10, 1946, show angulation. Function is good.

FIG. 4

This patient, injured March 17, 1945, was operated upon August 24, 1945. These roentgenograms of the radius were taken on February 2, 1946. Strength and function are good.

FIG. 5

FIG. 6

Fig. 5: Patient was injured December 23, 1944; operation on femur was performed November 2, 1945. These roentgenograms were taken March 15, 1946. The patient is walking with a caliper brace.

Fig. 6: Injury was received July 2, 1944; the femur was operated upon July 24, 1945. Anteroposterior roentgenogram was taken on February 27, 1946. The patient is walking with a caliper brace.

TABLE I

CASES IN WHICH OPERATION WAS PERFORMED

Location of Injury	No. of Cases	Location of Injury	No. of Cases
Femur	8	Clavicle	3
Tibia	5	Humerus	8
Fibula	3	Radius	9
Metacarpal	5	Ulna	11

subperiosteally, above and below the defect. Interposed scar tissue should be removed completely with a sharp periosteum elevator or a gouge; it can best be removed *en masse*. The sclerosed ends of the fragments are perforated into the medullary cavity, and the end which is to receive the bone graft is opened well and enlarged, if necessary. The main fragments are aligned, and a careful examination is made to determine the most suitable site of application, and the size and shape of the proposed graft. Obstructing bone projections are excised, and other necessary trimming is carried out. A suitable graft is removed from the tibia. A long graft which extends 7.5 centimeters beyond the fracture site is advisable, because it gives better early stability and can be fastened with screws, well away from the fracture site. The graft is fashioned at one end so as to fit snugly into the intramedullary space previously prepared in one fragment; and it is then rotated, so

that its flat surface rests with maximum coaptation on the cortex of the other fragment. In some cases it may be necessary to prepare a partial groove for the onlay portion, as in the classical inlay procedure. The graft is tapped firmly and snugly into the intramedullary space of one fragment; its flat surface is clamped to the other fragment, where it is fixed firmly with stainless-steel screws. These screws are placed quite far distant from the fracture site, and are passed through both cortices of the underlying fragment. If the intramedullary portion of the graft is placed in loose cancellous bone—as, for instance, in the proximal end of the humerus—a transfixion screw may be necessary to prevent movement. Finally, bone chips from the upper end of the tibia or from the ilium are packed around the graft and into the defect, so as to fill vacant spaces. Early stability is accomplished, so that the danger of displacement during closure and the application of the cast is obviated. Soft tissues are closed in the usual manner, care being taken in the placement of sutures not to produce undue tension. A snug-fitting, well-molded cast is applied.

FIG. 7

FIG. 8

Fig. 7: This patient, injured January 7, 1945, was operated upon July 30, 1945. Roentgenograms were taken April 1, 1946. The patient is walking with a brace.

Fig. 8: Injury was received November 11, 1944; patient was operated upon June 1, 1945. Roentgenograms of the leg were taken March 23, 1946. The function is excellent.

POSTOPERATIVE CARE

After operation, the principal problem is prevention of swelling, and it is of paramount importance to elevate the extremity. Immobilization is continued in a snug plaster cast for several months. A change of cast is essential whenever there is loosening, which occurs as a result of muscle atrophy.

An estimate of the period of maximum weakness of the graft is between three and six months after its insertion. A study of the roentgenograms suggests that the convalescent period necessary for the bone graft to become strong enough to safely assume function is much longer than was estimated heretofore. This period varies greatly in different individuals, and also according to the location of the fracture and the placement of the graft.

The method has the following advantages:

1. Maximum coaptation of the graft to the fragment is achieved readily.
2. A minimum of foreign material is necessary.
3. The graft is applicable in locations in which massive onlay grafts would be cumbersome and not feasible.
4. There is no sequestration of the graft.

The operation was performed in a series of fifty-two cases at Battey General Hospital (Table I). Early complications were encountered in ten cases:

1. In three cases, fracture of the graft occurred, because of too early removal of the immobilization.
2. Rarefaction around the screws was encountered in two cases. This was thought to be due to electrolytic action, since metal fragments were present in the soft tissues.
3. In one case, the graft projected into the joint at operation, when it was inadvertently driven through the lower end of the radius. Later this portion (one centimeter) was removed. No joint injury resulted.
4. A sinus formed through a scar in two cases, with postoperative infection. The infection was mild and did not interfere materially with the bone and callus formation.
5. Angulation in cancellous bone was present in one case.
6. Fracture of the donor site in the tibia occurred in one case.

LATE REPORTS ON THE CASES OF INTRAMEDULLARY ONLAY GRAFTS

Follow-up reports with roentgenograms were obtained on forty-two of the fifty-two patients. The sources of information were orthopaedic surgeons at Army General Hospitals and Veterans Hospitals, orthopaedic surgeons who were treating discharged veterans, roentgenographic laboratories, and individual patients. A résumé of the findings is as follows:

Reports were received on all three cases of grafting of the clavicle. Good healing occurred in all.

Of the eight humerus cases, good healing took place in four. One bone healed with angulation, but with good function. Three were unsuccessful because of (1) absorption of the graft; (2) failure of "take"; and (3) fracture followed by absorption of the graft. In one case, which previously had been reported as unsuccessful because of fracture of the graft, the graft finally united after a long period of immobilization.

Reports were received on seven of the nine radius cases. In five, the grafts had been successful; two were failures. Of the two failures, one bone was ununited after five months, and absorption of the graft after five months was reported in the other.

Of the eleven ulna cases, reports were received on seven. Six grafts were successful; one had non-union eight months after operation.

Of the five cases of metacarpal grafting, healing took place in four. One graft was fractured by too early manipulation of the finger, followed by absorption of the graft.

Reports were received on six of the eight femur cases. Four grafts were successful; two

FIG. 9

This patient was injured in the hand January 27, 1945, and was operated upon June 18, 1945. Roentgenogram, taken March 15, 1946, shows absorption of graft, applied to the metacarpal.

TABLE II

UNSUCCESSFUL RESULTS FOLLOWING OPERATION

Complication	Location	No. of Cases
Fracture of graft	Femur	1
Fracture and absorption	Humerus and metacarpal	2
Absorption	Humerus and radius	2
Non-union of graft	Humerus, radius, and ulna	3
Delayed union	Femur	1

were unsuccessful. One patient suffered a fracture of the graft six months after operation, and one was still in traction eight months after operation.

Of the five tibia cases, reports were received on three. Two grafts healed well; one had moderate union eleven months after operation.

Good healing occurred in all of the three fibula cases.

A follow-up study of these forty-two cases leads to the following observations:

1. The graft undergoes a process of atrophy during its early period,—namely, for three to five months after its insertion. Evidence supporting this belief is (a) increased radiolucency, as seen in the roentgenograms; (b) the accidental fracture of the graft in several cases, after considerable time had elapsed; and (c) a feeling of weakness in the grafted area for several months. The atrophic process resulted in increased fragility and secondary fractures, noted in several patients, and in absorption of a portion or the whole of the graft in others.

2. The graft does not possess osteogenic power when implanted, but it may take on this property later, or after a process of reconstitution takes place. Evidence to support this belief is the union of the fractured graft following a long period of immobilization.

3. Proliferation of the bone, as observed from late roentgenograms, seems to arise from the adjacent fragments. The bone-forming process apparently extends along the graft at some time after the graft undergoes so-called reconstitution. Later the graft itself increases in size.

4. In no case was there evidence to support the belief that the intramedullary portion of the graft causes atrophy or deterioration of the fragment into which it has been implanted.

SUMMARY

Of the fifty-two patients operated upon, follow-up studies were obtained in forty-two. Satisfactory results were reported in thirty-three cases. The unsatisfactory results observed in the remaining nine cases are recorded in Table II.

NOTE: The author wishes to acknowledge with deep appreciation the assistance and cooperation of Captain Leo Markin, M. C., and Captain Robert Hampton, M. C., Assistant Chiefs of the Orthopaedic Service at Battey General Hospital.

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WEDGE OSTEOTOMY OF THE SPINE WITH BILATERAL INTERVERTEBRAL FORAMINOTOMY

Correction of Flexion Deformity in Five Cases of Ankylosing Arthritis of the Spine

BY HENRY BRIGGS, M.D., SIDNEY KEATS, M.D., AND PHILIP T. SCHLESINGER, M.D.,
ORANGE, NEW JERSEY

From the New Jersey Orthopaedic Hospital, Orange

The treatment of flexion deformity of the spine, associated with ankylosing spondylitis, presents a difficult problem. Very frequently, flexion deformity of the spine develops, despite vigorous systemic antirheumatic therapy and adequate bracing of the back. Such a patient often presents an arcuate kyphosis in the thoracolumbar region, with loss of the normal lumbar lordotic curve. The patient stands with hips and knees in flexion; the whole trunk, as well as the head and neck, is thrust forward. The thorax is flat and appears immobile; respiration is frequently almost exclusively abdominal. As this chronic, painful condition progresses, loss of weight, anaemia, and the typical pinched, drawn facies appear.

The significant pathological feature is the involvement of the intervertebral articulations with the ensuing ankylosis of the spine. A gradual ossification of the interspinal ligaments, the anterior and posterior longitudinal ligaments, the ligamenta flava, and the capsular ligaments of the apophyseal joints follows, to a varying degree. The ossification of the anterior longitudinal ligament is characteristically seen early in the Marie-Strümpell type of ankylosing spondylitis. This ankylosis eventually limits the deformity, but also precludes satisfactory correction of the deformity by conservative measures.

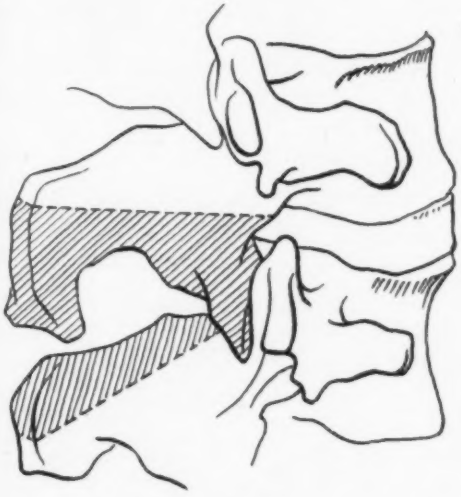

FIG. 1

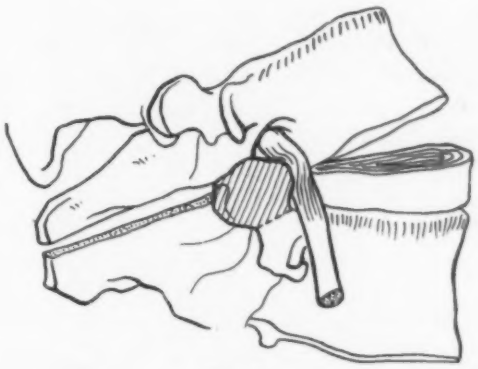

FIG. 2

Fig. 1: The wedge-shaped pattern of the posterior elements resected in osteotomy of the spine includes a portion of the spinous processes, laminae, articular processes, and pedicles of the contiguous vertebrae.

Fig. 2: Illustrating the mechanism of compression of the roots in the intervertebral foramina by the superior articular process of the inferior vertebra, when hyperextension is effected beyond the normal range. The shaded segment indicates the amount of the process and pedicle removed in completing the foraminotomy.

Since the original description of osteotomy of the spine for the correction of flexion deformity in rheumatoid arthritis by Smith-Petersen, Larson, and Aufranc, the authors have developed a different operative technique in a series of five patients operated upon at the New Jersey Orthopaedic Hospital. It is our purpose to present a preliminary report of these cases.

The new technique consists of a wedge resection of the posterior elements of the spine (Fig. 1). This wedge includes a portion of the spinous processes, laminae, articular processes, and pedicles of the adjacent vertebrae. This procedure is, in actuality, a wide bilateral foraminotomy, as previously described by Briggs and Krause. The advantage of this operation is that a satisfactory correction of the deformity may be obtained at one operation and at one level.

The mechanism of the operation may be clearly demonstrated on the cadaver. Such a study shows that the amount of correction depends entirely upon the size of the wedge removed. As correction is obtained, the fulcrum, or pivot of angulation, is along the posterior margin of the intervertebral disc, usually at the superior border. As more than a normal hyperextension is gained, the superior articular process of the vertebra below compresses the roots in the intervertebral foramina at this level against the disc and vertebral body. The removal of the superior articular process of the vertebra below, with some of its pedicle, frees the nerve roots from impingement and allows for a degree of correction beyond normal hyperextension (Fig. 2).

We wish to present the operative procedure employed. The lower lumbar region is selected for the site of osteotomy, which, we believe, should be performed where the anterior longitudinal ligament is well calcified. It is helpful to make a roentgenogram preoperatively, with a marker placed on the patient to identify a lumbar vertebra.

FIG. 3-A

Case 1, K. D. B. Preoperative roentgenogram.

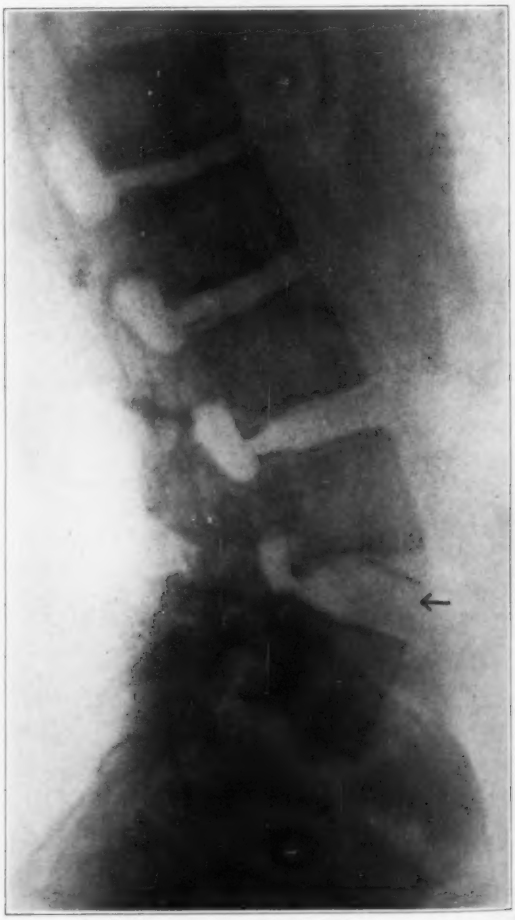

FIG. 3-B

Postoperative roentgenogram.

FIG. 4-A
Case 2. G. A. Preoperative roentgenogram.

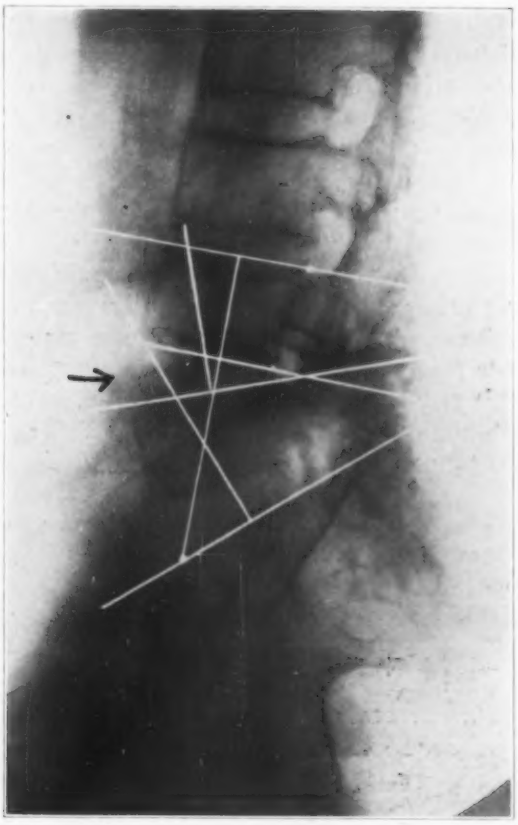

FIG. 4-B
Postoperative roentgenogram.

The patient is placed on the table in the prone position with sandbags and pillows on each side, so that the abdomen is not compressed by the weight of the body. This allows free diaphragmatic breathing and tends to reduce epidural hemorrhage.

A mid-line incision is made, and the tissues are reflected from the laminae, spinous processes, and articular processes by subperiosteal stripping. Exposure is made from the first sacral segment to the second lumbar. This facilitates the necessarily wide exposure. On identifying the site of osteotomy, assumed for description to be between the third and fourth lumbar vertebrae, the articular processes at that level are exposed, and the lateral borders of the third lamina are identified. A coronal section is then made with the osteotome and bone-cutting forceps through the spinous process of the third lumbar vertebra and directed so that ultimately the entire inferior articular process of this vertebra and some of the lamina superior to it will be removed. Another section is then made through the spinous process of the fourth lumbar vertebra and is directed obliquely cephalad toward the apex of the first section, so that a 45-degree wedge of bone will be removed with its base posterior. This wedge will ultimately include the superior articular process of the fourth lumbar vertebra and some of the superior portion of its pedicle. This section of bone, which is usually somewhat decalcified and may be sectioned and curetted with ease, is then broken out down to the ligamentum flavum, which is usually well calcified. The ligamentum flavum is then removed, exposing the dura and the nerve roots at that level. With osteotome and curettes, the remainder of the articular processes and a portion of the pedicle below on each side are removed, which completes the wide foraminotomy and gives a thorough exposure of the nerve roots. Epidural bleeding must be controlled.

The pillows and sandbags are next removed, and downward pressure is made on the lumbar spine by the operator. A certain amount of "give" takes place with steady pressure. Frequently a firm thrust has to be made, which is usually followed by a snap, when the anterior longitudinal ligament ruptures. At this point the correction is apparent and is maintained. The contiguous borders of the vertebrae are now in contact.

During this manoeuvre, one has the impression that the lamina of the superior vertebra is angulating and is compressing the dura to an alarming degree. This phenomenon may be safely ignored, since we have found no evidence of compression of the dura and cauda equina at this point. The remnants of the laminae of the third and fourth lumbar vertebrae are then denuded of outer cortex by osteotomes, leaving a raw, bleeding, bony surface. A stainless-steel curved spine plate, as designed by Wilson[4], is then placed in a bony trough along the lateral surface of the spinous processes on the right side and is secured by means of bolts and elastic stop nuts to the spinous processes of the second and fifth lumbar vertebrae. (We have found that ordinary nuts tend to loosen and unwind.) Bone chips, prepared from the sections of bone previously removed, are then packed into the denuded laminal troughs on both sides of the spinous processes to effect a bony fusion between the third and fourth lumbar vertebrae, as described by Briggs and Milligan. The wound is then carefully closed in layers.

FIG. 5-A

Case 3, D. R. Roentgenogram taken before operation.

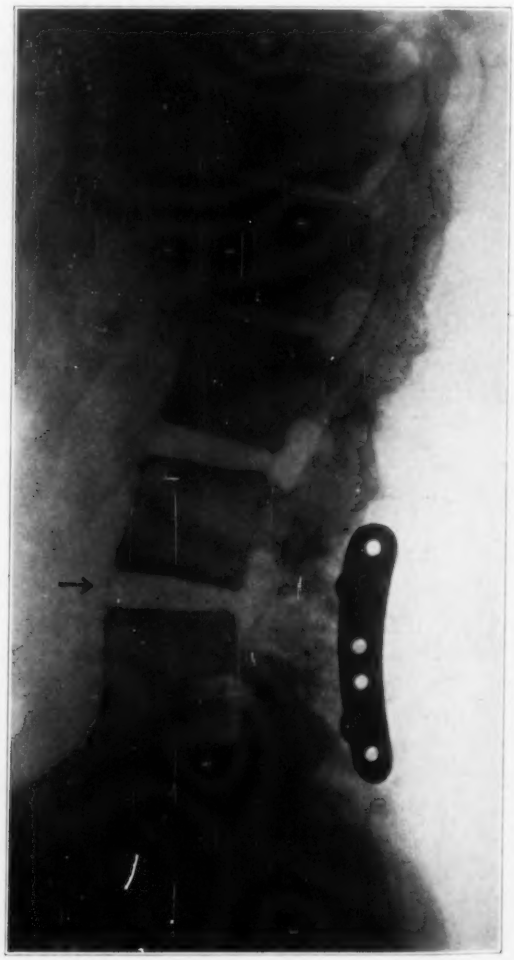

FIG. 5-B

Roentgenogram taken after operation.

During the operation, the patient is maintained on a continuous infusion of 5 per cent. glucose in saline; and a transfusion of 500 cubic centimeters of whole blood is at hand. After operation, the patient is placed in a supine position. After four to five days, a long Taylor spine brace is applied, which the patient wears at all times. After ten to fourteen days, the patient is permitted to be ambulatory and is advised to wear the brace continuously for a year or longer.

The technique as described represents the product of our cumulative experiences. Although this operation is a formidable procedure, it is technically feasible for one who is familiar with disc surgery.

CASE REPORTS

CASE 1. K. D. B., a white male, aged twenty-one, with a flexion deformity (Fig. 3-A) of five years' known duration, was operated upon February 28, 1945. Osteotomy of the spine was performed between the fourth and fifth lumbar vertebrae, with bony fusion of these segments (Fig. 3-B). The patient returned voluntarily for examination on January 8, 1946. He felt well and had no pain. Correction was well maintained. The patient was very well pleased with the improvement in his posture. The result was classified as excellent.

In this case, our first, we feared that we might have gained too much correction, and that, when fusion had occurred, the head might be tipped too far backward, and the patient might not be able to look directly forward. About a week after operation, a Taylor brace was applied, and the patient was helped to a standing position at the side of the bed. It was then noted that his posture was entirely satisfactory.

FIG. 6-A

Case 4, T. T. Preoperative roentgenogram.

FIG. 6-B

Postoperative roentgenogram.

Fig. 7-C

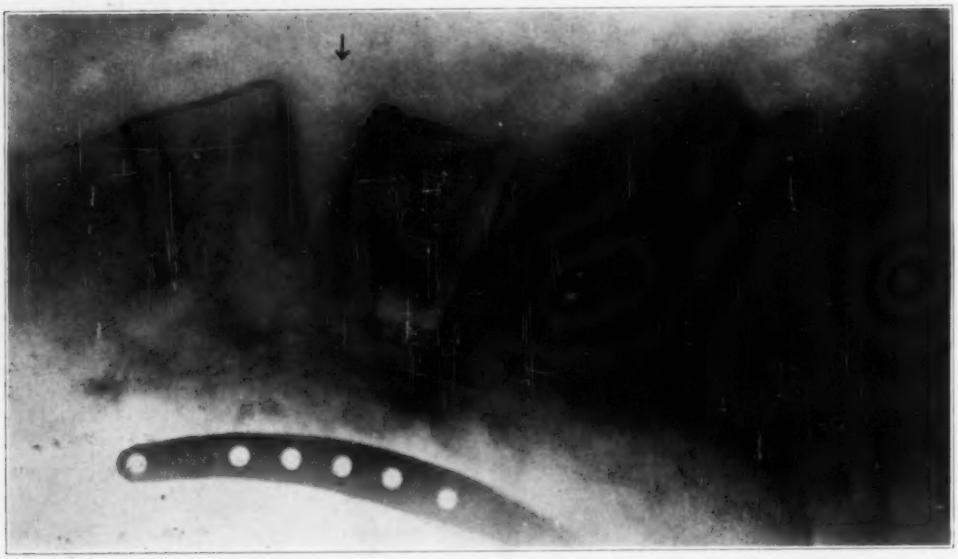

Fig. 7-B

Figs. 7-B and 7-C: Roentgenograms taken after operation.

Fig. 7-A

Fig. 7-A: Case 5, M. N. Preoperative roentgenogram.

Case 2. G. A., a white male, aged thirty-six, with a deformity of about eight years' duration (Fig. 4-A), underwent an osteotomy of the spine, on May 19, 1945, involving the fourth and fifth lumbar vertebrae, with chip fusion of these segments (Fig. 4-B). When again examined, November 12, 1946, he seemed to have gained weight and had no pain or discomfort although he appeared to have lost some of the correction. Ankylosis of the hips was progressing, and he was using a cane. At that time, he was employed as an inventory clerk. The result of the operation was classified as fair.

In this case, the correction at the operation seemed to be adequate, although no snap of the anterior longitudinal ligament was heard. Roentgenograms taken immediately after the operation showed a 34-degree correction. A spine plate was not used. Roentgenograms taken eighteen months later showed almost complete loss of correction. This indicated that, unless the anterior longitudinal ligament ruptures, correction cannot be maintained without internal fixation.

Case 3. D. R., a thirty-year-old white male, had a deformity of eight years' known duration. A lumbosacral fusion for a painful back had been performed three years previously at another hospital. One of the preoperative roentgenograms is shown in Figure 5-A. On November 14, 1945, osteotomy of the spine was performed between the third and fourth lumbar vertebrae, with chip fusion of these vertebrae. A spine plate of the Wilson type was applied to the spinous processes (Fig. 5-B). The patient was again examined November 12, 1946. At that time, he was working as an assembler. He had some pain at the upper end of the incision and felt that he was losing the correction, although he appeared to have retained some of the initial correction. The result was classified as fair.

In this case, in spite of a vigorous downward thrust, with the head and foot of the table elevated, no snap was heard or felt, and the back seemed to spring back to its original position when the pressure was released. For this reason, a spine plate was applied. Roentgenograms showed that some correction had been obtained, but it has not been maintained. The site of osteotomy in this case was not chosen where the anterior longitudinal ligament was well calcified. Because of this experience, we now feel that the osteotomy site should be chosen where the ligament is well calcified.

Case 4. T. T., a colored female, aged twenty, with a known duration of symptoms of two years (Fig. 6-A), was operated upon January 16, 1946. Osteotomy of the spine was performed between the third and fourth and the fourth and fifth lumbar vertebrae, with bony chip fusion from the third to the fifth lumbar vertebrae (Fig. 6-B). On November 12, 1946, the patient had no pain. Correction had been maintained, despite a fall from the second-story window two months postoperatively. The patient was pleased with the result of the operation.

This back was corrected very easily at operation, and a snap, indicating that the anterior longitudinal ligament had ruptured, was heard. When the correction had been obtained, it appeared that the lamina of the fourth lumbar vertebra was angulating downwards, compressing the cauda equina. This situation had been noted before. To check the condition, the whole fourth lamina was slowly removed, but no actual compression of the dura by the border of this lamina could be found. After the operation, the patient was watched carefully for evidence of root compression, but gave no indication of such compression.

Case 5. M. N., a white male, aged thirty-eight, had a deformity of fourteen years' known duration (Fig. 7-A). On May 22, 1946, osteotomy of the spine was performed between the third and fourth lumbar vertebrae and a spine plate was applied, with subsequent bony fusion of the vertebrae (Figs. 7-B and 7-C). When examined on November 12, 1946, the patient was considerably improved. Correction had been maintained, and the patient was working in a gasoline filling station. He had no pain and was well satisfied with the improvement in his posture. The result was classified as excellent.

When the anterior longitudinal ligament ruptures, as in this case, one is impressed by the instability of the spine and the possibility of the slipping of one vertebra on the other at the osteotomy site. This seemed to be a dangerous situation, because of the possibility of injury to the cauda equina. However, as soon as the Wilson-type spine plate had been applied, stabilization of the involved segments was established. The value of internal fixation was then very apparent.

Figs. 7-B and 7-C: Roentgenograms taken after operation.

Fig. 7-A: Case 5, M. N. Preoperative roentgenogram.

This operation was performed by the technique described, with a successful result, as demonstrated by the roentgenograms. We encountered some immediate difficulty in this case; the patient was placed on his back following the operation, and every time he was turned onto his side, he showed respiratory embarrassment and had to be turned immediately onto his back. This seemed to be due to pressure on the abdomen and interference with abdominal breathing.

Patients with severe ankylosing arthritis of the spine have very little, if any, excursion of the thoracic cage in respiration, and any changes in intra-abdominal pressure, which might interfere with diaphragmatic motion, are dangerous. This case indicates the importance of maintaining the patient in the supine position postoperatively.

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DISCUSSION

(*Continued from page 1067*)

Dr. J. Albert Key, St. Louis, Missouri: In our series at the St. Louis City Hospital, the mortality of trochanteric fractures was 43 per cent. when we treated these cases conservatively. When I first started, I thought I could nail a trochanteric fracture as I would a fractured neck. This procedure must be carried out on a fracture table. The fracture must be reduced by mechanical traction, and the reduction must be checked with the roentgenogram, which is easier than in the case of the fractured neck, because the extremity can be brought out to the plate. The operation can be most easily carried out under general anaesthesia, and the mortality will be less than that obtained with conservative treatment.

Dr. Frederick R. Thompson, New York, N. Y. (closing): I have very little to add except to thank the discussors,—Drs. Diveley, Norton, Bosworth, and Key. We did not operate upon these patients with fractures under traction. We used the usual operating table. Although many fractures can be reduced by manipulating the lower extremity before operation, some require reduction at the time of operation.

CONGENITAL DISLOCATION OF THE PATELLA

Case Report with History of Four Generations

BY E. B. MUMFORD, M.D., INDIANAPOLIS, INDIANA

It is not the purpose of this discussion of a congenital dislocation of the patella to give a historical review of the anatomical and embryological factors which differentiate the congenital type of dislocation, a constant condition, from the recurrent type of dislocation, a changing condition. These phases of the subject have been covered thoroughly by Conn in his carefully prepared presentation of a plan of operation for the congenital type of dislocation.

Conn does not give a detailed description of the changes, if any, noted in the knee joint at the time of operation. His comment on this phase of the study was: "The exposed capsule revealed a small patella lying with its articular surface apposed to the lateral surface of the external femoral condyle, in which position it was anchored by the shortened fibers of the external capsule". The roentgenogram was essentially negative.

That changes within the internal structure of the knee joint may occur, especially in old cases, may be seen from Figures 1-A and 1-B (a left knee) and Figures 2-A and 2-B (a right knee). These two cases represent the congenital type of dislocation; some pain had been present since early childhood. Each was a female, one sixty years and one seventy years of age. Each refused an operation. The changes seen in Figures 1-A and 1-B are very extensive, and show not only progressive changes in the femoral and tibial condyles, resulting from a long period of faulty weight-bearing, but also osteochondritic changes, with the formation of loose bodies and a thinning of the articular cartilage.

CASE REPORT

V. M., a white woman, aged twenty-five and in good health, was first seen by the author on July 1, 1936. Her complaint was pain and instability in each knee. She gave the following history: The first time she could remember having trouble with her knees was between the ages of six and seven. She was a very healthy child, and strong in every way except for her knees. She would try to play games with the other children, but could not always do so. For a week she might not have any trouble, and then she would have pain and instability

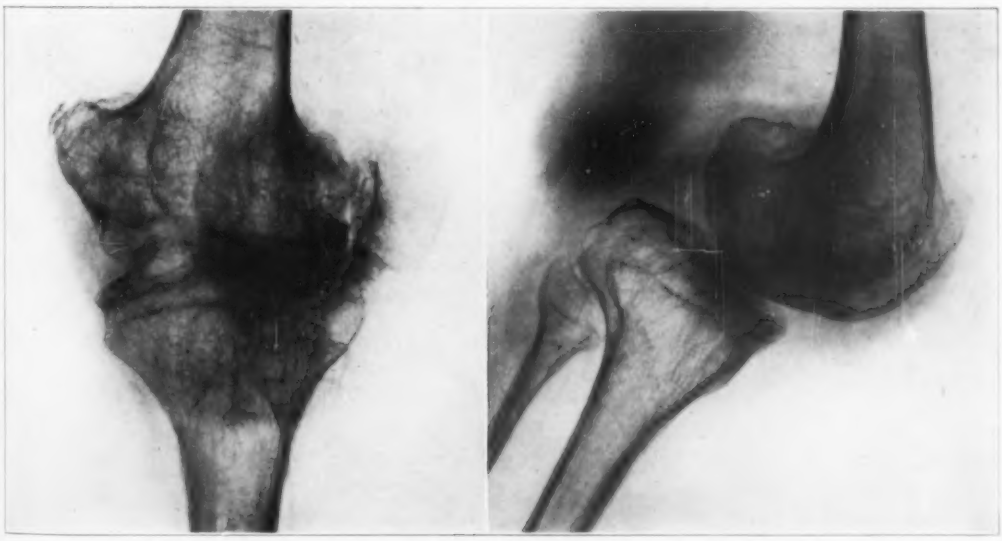
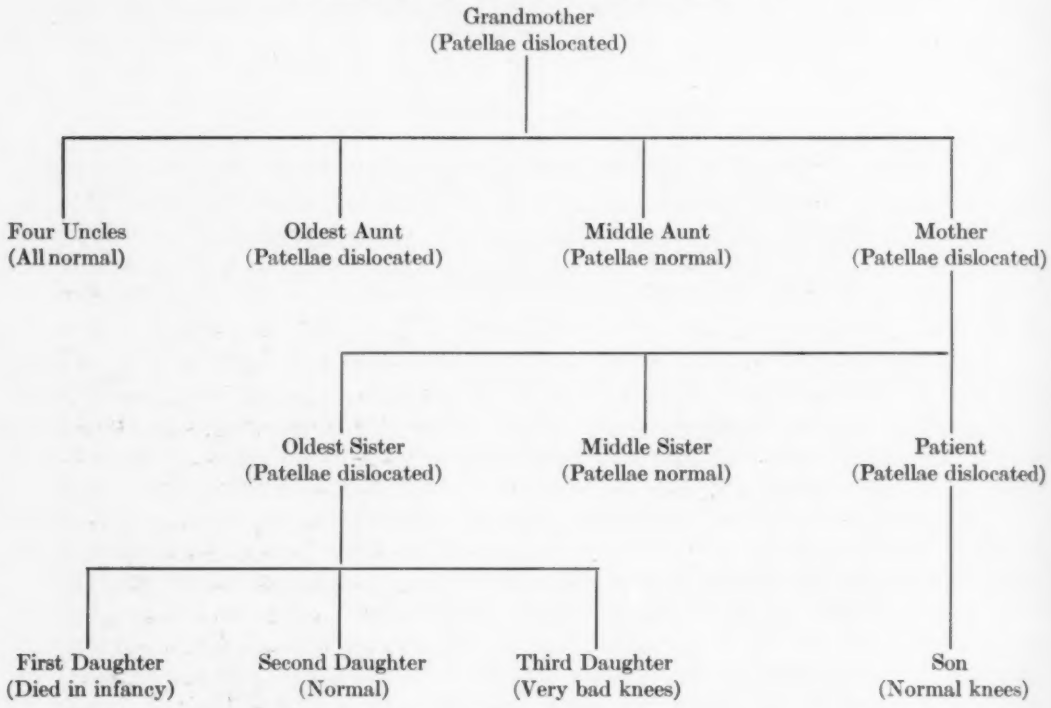


FIG. 1-A FIG. 1-B

Congenital dislocation of left patella in M. C., a woman, sixty years of age.

CHART I

HISTORY OF MATERNAL RELATIVES OF PATIENT



in each knee, day after day. At times, when the knee would turn to the side, it would hurt so much that she could not play and had difficulty in walking, but there would not be any swelling. At other times, she would fall, the knee would become swollen, and she could not walk for a long time. The amount of injury seemed to be related to the position of the legs at the time of the fall. As she grew older her knees turned more and more and her legs became weaker, so that she could scarcely walk without falling. At the time of the examination, she had to use crutches.

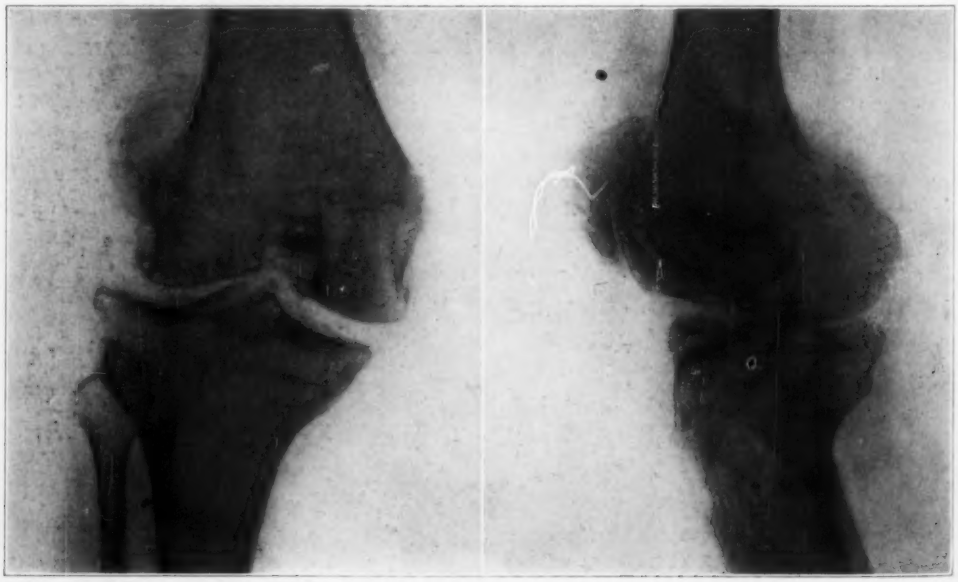


FIG. 2-A FIG. 2-B

Congenital dislocation of right patella in O. T., a woman, seventy years of age.

Family History: In this unusual family history a "knee condition" existed in four successive generations (Chart I), and was described by the patient as being similar to that of her own knees. (None of the other members of the family were seen by the author.) All of the knee conditions occurred in the females, and none in the four males of the second generation (uncles of the patient) or in the patient's son (fourth generation). In both the second and third generations there were three females, but the knee condition was present in only the oldest and the youngest of each of these generations, the middle female having normal knees. In the fourth generation, the youngest daughter has "very bad knees".

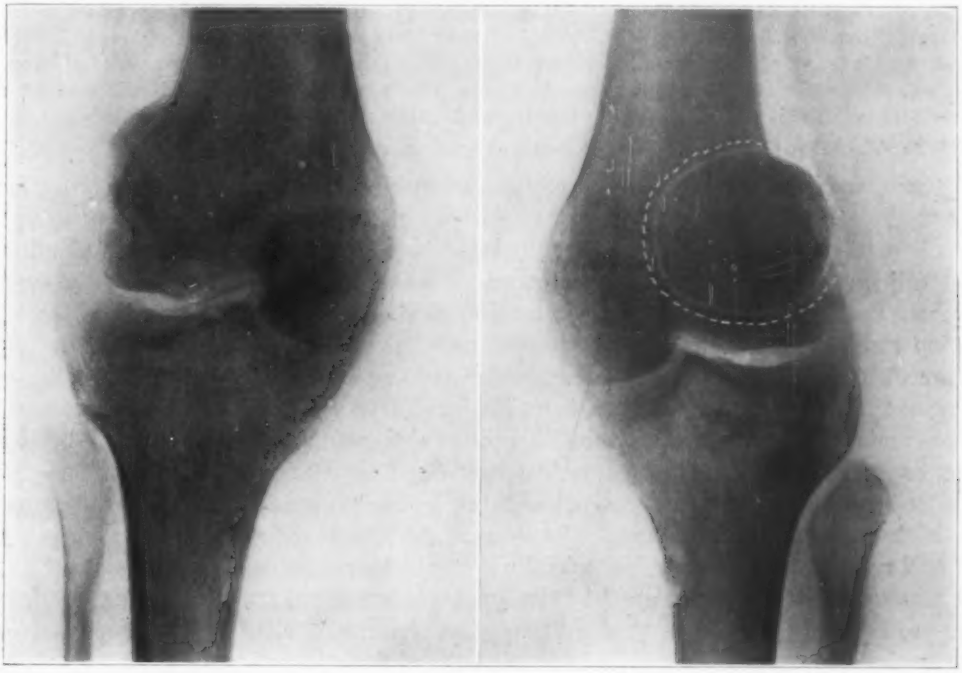


FIG. 3-A

Roentgenograms of V. M., aged twenty-five, taken before operation.

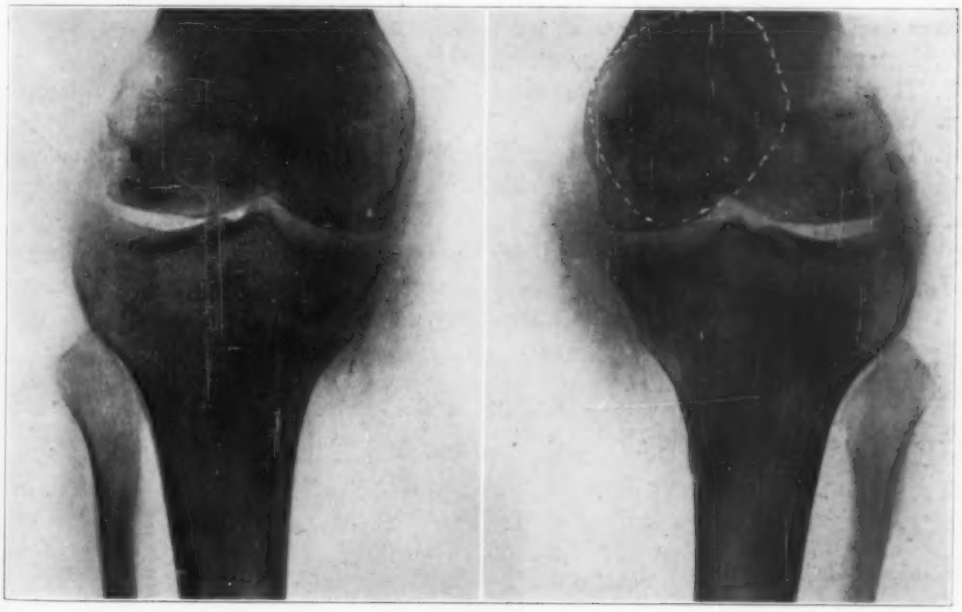


FIG. 3-B

Postoperative roentgenograms of same patient, taken on April 25, 1938.

Roentgenograms of the patient (Fig. 3-A) showed lateral displacement of the patella; the presence of a small loose body beside the lateral femoral condyle; and a depression in the condyle, corresponding to the size and position of this body. The roentgenographic diagnosis of dislocation of the patella was confirmed by physical examination, as well as at operation, and the case was classified as the congenital type.

The author's experience with the Goldthwait method of operation for recurrent dislocation of the patella had been so satisfactory in fourteen knees that this operation was done on each knee of this patient on August 4, 1936. However, as might have been determined if the operator had had more knowledge on the subject, the operation was of no value. On September 23, 1937, the right knee was operated upon according to the method of Conn, and the result was so satisfactory that the patient requested a similar operation on the left knee; this was done on November 19, 1937 (Fig. 3-B). The convalescence from each operation was uneventful, although slow as regards return of function and stability. At the end of one year the patient resumed her household duties, and six months later she returned to factory work. She had good stability, and no pain in either knee. A recent report (1946) is that the patient now has normal function in the knees, that there has been no recurrence of either pain or instability in the knee joints, and that she considers herself entirely well.

The operation suggested by Conn is logical in its development, and not too difficult in execution. The knee capsule is exposed by reflecting the skin flap. A longitudinal incision is made external to the patella, through the capsule and the synovial membrane. The tendinous attachments of the vastus lateralis and the vastus medialis of the quadriceps mass are freed from the quadriceps tendon itself. The patella is pushed into its normal position in the mid-line, which leaves a diamond-shaped gap in the line of the lateral incision. A piece of similar shape (which conforms to a piece of tinfoil placed over this gap) is then cut from the redundant capsule on the inner aspect of the joint, which includes the capsule and the synovial membrane. This piece is transferred to the gap on the lateral aspect and sutured in place with chromic catgut No. 1, care being taken to pass the sutures down to, but not through, the synovial membrane. The incision on the inner aspect of the joint is closed with similar sutures. The elongated fibers of the vastus medialis are shortened and sutured to the quadriceps and the upper border of the patella, the already shortened vastus lateralis is reattached to the quadriceps tendon, and the flaring quadriceps fibers are folded under the severed portion of the tendon. Weight-bearing is permitted in three weeks, and full use of the limbs is encouraged during the fourth week.

CONCLUSIONS

1. Congenital dislocation of the patella presents an entirely different operative problem than does the recurrent type of dislocation.

2. Extensive joint changes may occur as the condition progresses.

3. The operation of Conn for congenital dislocation of the patella offers a satisfactory prognosis.

4. The family history of a "knee condition" in four successive generations suggests an element of heredity on the maternal side.

NOTE: Since this article was written, roentgenograms have been obtained of the knees of the oldest aunt of this patient and of the youngest daughter of this aunt. These roentgenograms show definite dislocation of each knee.

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DIAGNOSIS AND TREATMENT OF TARDY PARALYSIS OF THE ULNAR NERVE

Based on a Study of 100 Cases *

BY JAMES R. GAY, M.D., AND J. GRAFTON LOVE, M.D., ROCHESTER, MINNESOTA

From the Sections on Neurologic Surgery, Mayo Foundation and Mayo Clinic, Rochester

Tardy paralysis of the ulnar nerve is a chronic affection which is caused by a wide variety of pathological conditions in the region of the elbow joint. Its course is characterized by slow progression. Surgical intervention is the only satisfactory form of treatment. Since the ulnar nerve is superficial and, therefore, easily exposed to trauma at the elbow, any condition which alters the relationship of the components of the elbow joint is likely to stretch or to irritate the nerve. Transplantation of that part of the nerve anterior to the medial epicondyle into a muscle bed is the specific surgical procedure which has provided the best results. Serious consideration of all diseases and injuries of the elbow and prompt treatment of these conditions are the best means of preventing the occurrence of this type of paralysis.

One hundred patients with tardy ulnar-nerve paralysis, seen consecutively at the Mayo Clinic in the past twenty-five years, are the basis of this study. All except one of the patients were treated by surgical methods. This large group of patients provided statistically sound information in regard to the etiology, prophylaxis, diagnosis, and treatment of this disease. Ten cases will be reported here to illustrate the wide variety of etiological factors which cause tardy ulnar-nerve paralysis.

The first case of tardy ulnar-nerve paralysis in the literature was reported in 1878 by Panas, who presented a paper before *l'Académie de Médecine* in Paris. J. B. Murphy published the first American contribution in 1914. Davidson and Horwitz have published an excellent review of the literature.

Many authors have presented classifications of paralysis of the ulnar nerve, resulting from trauma, in which the nerve trunk remains intact. A combination of these classifications, which was found useful for the purpose of this study, is shown below:

A. Primary and secondary ulnar neuritis resulting from:
   1. Simple contusion;
   2. Recent fracture of the humerus, either of the medial epicondyle or in the supracondylar region;
   3. Recent dislocation of the elbow joint.

B. Tardy paralysis of the ulnar nerve, due to involvement of the elbow region by:
   1. Old fracture;
   2. Arthritis;
   3. Occupational trauma;
   4. Congenital anomalies;
   5. Old or recurrent dislocations;
   6. Tumors;
   7. Unknown factors.

ETIOLOGICAL ASPECTS

Most of the etiological information in the literature appears to be based on a relatively small number of cases. The authors have been impressed with ancient fractures of the elbow as exclusive causes of tardy paralysis of the ulnar nerve. In this study of 100 cases it was possible to make an analysis of the etiological factors involved, and to discover a wide range of circumstances which produce this condition.

* Read before the Harvey Cushing Society, Boston, Massachusetts, October 10, 1946.

TABLE I

OCCURRENCE OF TARDY PARALYSIS OF ULNAR NERVE ACCORDING TO OCCUPATION

Occupation	No. of Patients
Professional and managerial	17
Clerical and sales	21
Service	21
Agriculture, fishing, forestry, and mining	24
Skilled labor	12
Semiskilled labor	0
Unskilled labor	5
Total	100

Tardy paralysis of the ulnar nerve was found to be a disease of adult life. The average age of a patient was thirty-eight years. Seventy-five per cent. of all the patients were more than thirty years old; only five were found who were less than twenty years old. The youngest patient was sixteen years old and the oldest, seventy-three years.

Men were more frequently afflicted with this condition than women by a ratio of four to one.

Tardy paralysis of the ulnar nerve did not appear to be especially likely to develop among members of any particular occupational group. Just as many so-called "white-collar" workers had this disease as persons engaged in heavy physical labor (Table I).

The right hand was most commonly affected. In 53 per cent. of the cases, paralysis occurred on the right; in 36 per cent., paralysis occurred on the left; the condition was present bilaterally in 11 per cent. of the cases. In all of the cases in this series, paralysis was caused by disease or injury which affected the ulnar nerve in the region of the elbow joint.

FIG. 1

Fig. 1, *a:* Left arm and hand of patient who had tardy paralysis of the ulnar nerve, demonstrating cubitus valgus, prominence of the lateral condyle of the humerus, and effects of atrophy of the intrinsic muscles of the hand. The condition was caused by an old fracture of the lateral condyle of the humerus, with non-union of fragments.

Fig. 1, *b:* Anteroposterior view of the left elbow.

An old fracture of the elbow was the leading pathological condition which caused tardy paralysis of the ulnar nerve (Table II). More than three fourths of the fractures involved the humerus; and the lateral condyle was the specific site in about half of the cases of fracture (Fig. 1). In every case of fracture, there was a history of injury. The average interval between the injury and the onset of symptoms was twenty-two years. The shortest interval was four months; the longest was sixty years.

Arthritis was the causative factor in 20 per cent. of the cases. In this group, two thirds of the patients gave no history of injury to the elbow. One patient had old gonococcal arthritis which involved the elbow joint; another had chronic arthritis, involving other joints in addition to the elbow.

FIG. 2-A

FIG. 3

FIG. 2-B

Fig. 2-A: Neuroma of the ulnar nerve removed from a patient (Case 8) who had tardy paralysis of the ulnar type. Proliferation of fibrous tissue had destroyed most of the nerve fibers.

Fig. 2-B: Section of the neuroma, removed from this patient. The few normal nerve fibers present are surrounded by dense fibrous tissue (Mallory phosphotungstic hematoxylin) (× 8).

Fig. 3: Multilocular ganglion cyst, arising from tendon in the olecranon fossa, which compressed the ulnar nerve and resulted in tardy paralysis of the nerve (Case 7).

TABLE II

ETIOLOGY OF TARDY PARALYSIS OF ULNAR NERVE

Cause	No. of Patients
Old fracture of elbow	57
Arthritis of elbow	20
Unknown	12
Occupational trauma of elbow	4
Congenital anomalies	3
Adhesions secondary to elbow injury	2
Cyst of elbow	1
Recurrent dislocation of elbow	1
Total	100

The majority of these patients, however, had hypertrophic arthritis of the elbow of unknown cause. Trauma of the ulnar nerve in the group with arthritis was caused by obliteration of the ulnar groove, which stretched and displaced the nerve, or by direct irritation in the form of spurs or loose bodies.

Twelve per cent. of the patients had no abnormality to account for the presence of tardy paralysis of the ulnar nerve.

TABLE III

SYMPTOMS IN ORDER OF FREQUENCY

Symptom	Occurrence (No. of Times)
Paraesthesia	85
Atrophy	81
Paralysis	62
Pain	39
Anaesthesia	25
Fibrillation	7
Tremor	3

In the remaining cases (11 per cent.), the disease was caused by miscellaneous conditions, such as congenital anomalies, occupational trauma, adhesions, ganglion cyst, and recurrent dislocations of the elbow joint.

PATHOLOGICAL ASPECTS

In most of the cases studied, a fusiform neuroma of the ulnar nerve was found at operation. Since the accepted treatment is transplantation without resection of the nerve, little information was available as to the microscopic pathological aspects of the affected nerve. One patient died from causes not related to this report, and the transplanted nerve was removed at necropsy. In another patient a large neuroma was removed, and end-to-end anastomosis of the nerve was performed. The gross and microscopic observations in this case are illustrated in Figures 2-A and 2-B.

According to Conway, the early stage of involvement consists of hyperaemia and oedema of the nerve. This is followed at a later stage by an increase in fibrous tissue. During this vicious process of hyperaemia, oedema, and proliferation of fibrous tissue which compresses the nerve fibers, the motor fibers appear to be more vulnerable than the sensory fibers. It must be assumed, in view of the favorable course in most of these patients, that removal of the source of trauma reverses the pathological process, in spite of the presence of a neuroma at the time of operation.

DIAGNOSIS

Probably the most characteristic feature of tardy paralysis of the ulnar nerve, other than its delayed appearance after trauma, is the development of profound atrophy of the intrinsic muscles of the hand, with relatively little or late impairment of sensation. Since wasting of the muscles in a hand is especially noticeable to a patient, most of the patients reported for treatment, even though they had only moderate disability from this condition. It was estimated that slightly more than half of the patients (51 per cent.) had 50 per cent. or less disability, as judged by the interference caused by their symptoms in the performance of their normal daily activities.

The average duration of symptoms was 2.9 years. The shortest duration in this series was two weeks; the longest, thirty-nine years. More than half of the patients had had symptoms for less than two years.

The predominating symptoms, in order of frequency, were paraesthesia, atrophy, and paralysis referable to the hand. Only a third of the patients complained of pain. Anaesthesia was a complaint in less than a fourth of the cases. Fibrillations and tremors were rarely observed by the patients (Table III).

On physical examination, the most common observations were atrophy and weakness of the hand; these were present in 96 per cent. of the cases (Table IV). Three fourths of the patients had an ulnar type of anaesthesia in the hand. Half of the patients had an

TABLE IV

PHYSICAL FINDINGS IN ORDER OF FREQUENCY

Finding	Occurrence (No. of Times)
Atrophy	96
Weakness	96
Anaesthesia	77
Enlarged nerve	51
Limited motion of elbow	48
Hypotonia	42
Deformity of elbow	39
Tender nerve	35
Tremor	9
Fibrillation	7
Shallow ulnar groove	8
Mass near ulnar groove	2
Painful elbow motions	1
Bilateral cervical ribs	1
Involvement of median nerve	1

enlarged ulnar nerve, but few of these patients had nerve tenderness. There was limitation of motion of the elbow joint in slightly less than half of the cases. Other observations frequently made were hypotonia of the muscles and gross deformity of the elbow. Tremor, fibrillation, a shallow ulnar groove, a palpable mass in the olecranon fossa, and pain on motion of the elbow were observed infrequently. In one case the concomitant finding of bilateral cervical ribs, and in another a simultaneous involvement of the median nerve, complicated the diagnostic pattern.

A study of these cases indicated that tardy paralysis of the ulnar nerve should be suspected in any case in which a patient complains of paraesthesia of ulnar distribution and exhibits wasting of the intrinsic muscles of the hand, regardless of whether or not sensory disturbances are present. The region of the elbow should be observed carefully, palpated, and manipulated in the search for pathological conditions which might account for dysfunction of the ulnar nerve. In this series, roentgenograms of the elbow joint were important, since many of the etiological factors were demonstrated prior to operation only by this means.

The principal conditions which may be confused with tardy paralysis of the ulnar nerve are the scalenus anterior syndrome, hypothenar neural atrophy[5], various intraspinal lesions, syringomyelia, and progressive muscle atrophy. Most of these conditions can be eliminated effectively by careful performance of physical and neurological examinations, and by evaluation of the results. The hypothenar neural atrophy described by Hunt deserves special mention. This condition is caused by chronic pressure on the deep palmar branch of the ulnar nerve. This branch is purely motor in function, and the paralysis is slowly progressive without sensory impairment. This is invariably an occupational disease.

PROPHYLAXIS

Tardy paralysis of the ulnar nerve could have been prevented in many of the cases in which a fracture of the elbow joint was the underlying cause. Prophylaxis would have involved more serious consideration of the injury to the elbow at the time it occurred.

Many of the fractures were either unrecognized or were inadequately treated. A typical history included a fall in childhood, which resulted in a bruised, swollen, and painful elbow. Usually, roentgenograms had not been taken, and the therapeutic program had consisted of the application of heat or cold, rest, and support of the injured arm across

the chest in pronation and acute flexion. Some degree of limitation of elbow motion had persisted, and ulnar paralysis had appeared insidiously in adult life.

In the treatment of recent fractures, it is suggested that, if open reduction is indicated and the surgeon anticipates a deformity of the elbow, prophylactic transplantation of the ulnar nerve may be performed at the same operation.

In the group of cases without fracture, the underlying pathological process was obscure to the patient; no prophylactic treatment was suggested by a study of these cases.

One case is reported here (Case 10) in which the only etiological factor was chronic occupational trauma. The patient was an accountant, who habitually rested his elbow on a desk. He was instructed to protect his ulnar nerve from such trauma and to perform restorative exercises of muscles supplied by the ulnar nerve. In this case, operation was avoided.

During long surgical procedures, with the patient in a supine position, it is a good technique to place small pillows between the patient's elbows and the operating table. This measure will prevent injury to the ulnar nerve.

TREATMENT

In general, the course of tardy paralysis of the ulnar nerve is characterized by unrelenting progression, and no known conservative form of treatment has been found to be of any permanent benefit. Best has written a good summary of the various forms of surgical treatment which have been employed. The following operations have been designed to prevent stretching of the nerve, to relieve sources of direct irritation, or to reverse the process of formation of neuroma.

The first operation is supracondylar osteotomy, which was adopted to shorten the humerus and to relieve pathological stretching of the nerve at the elbow. This was a formidable procedure which did not always accomplish its intended purpose, because of postoperative involvement of the nerve in scar tissue or the formation of osteoma.

The second operation is deepening of the ulnar groove, a procedure introduced to reduce tension of the nerve. This operation failed because the postoperative development of osteoma often obliterated the groove. Scar tissue then added insult to the nerve.

The third procedure consists of removal of bone fragments and loose osteocartilaginous bodies. This was designed to remove the source of direct irritation of the nerve. It proved to be an inadequate attack on the problem, unless the nerve was transplanted anteriorly at the same time. Additional loose bodies were especially likely to recur, and the damaged nerve did not recover unless maximum protection against stretching was provided.

The fourth operation is transplantation of the nerve anterior to the medial epicondyle of the humerus. This procedure has withstood the test of time. Most forms of trauma to the nerve at the elbow are relieved by this method. Flexion of the forearm in the presence of a deformed elbow causes pathological stretching of the ulnar nerve. After this operation, flexion of the elbow actually reduces tension on the nerve trunk. In addition, this method places the nerve at a distance from other sources of irritation at the elbow. The procedure introduced by Murphy[6, 7] consists of transplantation of the nerve into the subcutaneous tissue and its envelopment in a tube of fat and fascia. This technique provides fair results. The damaged nerve is readily traumatized, however, since the skin and subcutaneous tissues offer inadequate protection. Adson developed a method of transplantation of the nerve into a muscle bed. This was accomplished by sectioning the anterior portion of the adjacent flexor or pronator muscles of the forearm, and resuturing the muscles over the nerve trunk. This procedure offers better protection for the injured nerve, and has provided the most favorable results. The details of the technique were reported by Adson in 1918.*

* Suspension of the nerve in a sheath of fascia lata no longer is done. Otherwise, the Adson technique is followed.

TABLE V

SUMMARY OF TREATMENT IN 99 OF 100 CASES *

Surgical Procedure	No. of Times Employed
Anterior transplantation of ulnar nerve into intramuscular bed	95
Anterior transplantation of ulnar nerve into subcutaneous bed	4
Neurolysis	54
Removal of callus or of loose bodies	10
Drainage of wound	5
Release of adhesions	3
Application of cast	1
Freeing of median nerve	1
Removal of ganglion cyst	1
Manipulation of elbow	1
Section of anomalous artery and vein	1
Excision of neuroma and end-to-end anastomosis	1

* One patient was treated conservatively.

The fifth operation is neurolysis, performed to check the formation of neuroma. This procedure has a considerable empirical basis, in that severing or stretching of the tense transverse fascial fibers should relieve compression of the nerve fibers within the neuroma. The most common form of neurolysis consists in the making of longitudinal incisions in the outer connective-tissue layers of the neuroma. This is done at regular intervals in the circumference of the mass by the use of a sharp safety-razor blade. Another type of neurolysis consists of distending the nerve sheath by the injection of saline solution. The principle of this procedure is to stretch the transverse fibers over the neuroma. It would seem that this procedure would be less effective, since the stretching effect probably is nullified by the increased pressure within the mass.

The sixth procedure is resection of the neuroma and the performance of end-to-end anastomosis of the nerve ends. This procedure is carried out on the assumption that the neuroma actually is a tumor which permanently inhibits the return of nerve function. There is evidence in the literature and in the present study, however, to indicate that the size of the neuroma has little bearing on the degree of recovery which will be obtained after the primary causative factors have been eliminated. In only one case in this study was resection of the neuroma and end-to-end anastomosis performed. In this case, the patient had a neuroma of such unusual size that the nerve could not be manipulated or transplanted easily.

The seventh operation consists of combinations of the afore-mentioned treatments. The most common combination which was used in the present series of cases consists of anterior transplantation of the nerve into a muscle bed, neurolysis of the neuroma by multiple longitudinal incisions, and, occasionally, removal of a loose osteocartilaginous body.

The eighth procedure consists of a special attack on anomalous conditions, occasionally encountered. The best examples of cases in this study in which special techniques were utilized were the finding of an anomalous artery and vein, which compressed the ulnar nerve at the elbow, and a ganglion cyst which arose from the tendon and compressed the nerve (Fig. 3).

In the present study, 95 per cent. of the patients were treated by anterior transplantation of the nerve into a muscle bed. Subcutaneous transplantation was used in only 4 per cent. of the cases. Neurolysis was performed in 54 per cent. of the cases; and, in 10 per cent., loose bodies were taken out or callus was removed. A variety of other procedures,

which were instituted in addition to anterior transplantation of the nerve, are indicated in Table V.

Ether, administered by the open-drop method, was the anaesthetic agent chosen in 80 per cent. of the cases. In 14 per cent., brachial-plexus block anaesthesia was employed, and three patients in this group required some other type of anaesthetic as a supplement. A patient was rarely operated upon under pentothal-sodium or nitrous-oxide anaesthesia.

Davidson and Horwitz, as well as other authors, have recommended a vigorous program of physiotherapy after operative treatment. In the cases reported in this study, no special physiotherapy program was employed. Patients were instructed to use the arm and hand normally, but to avoid flexing the elbow against resistance, such as lifting or pushing a heavy object, for a period of three months. This advice was given to avoid tearing the common flexor attachment from the medial epicondyle, where it had been reattached by sutures at operation.

RESULTS

The results of surgical treatment for this condition were gratifying. In the 100 consecutive cases studied, 70 per cent. of the patients obtained a satisfactory result. This was judged by information which indicated that the patient was able to participate in his normal activities, that he had regained normal use of his hand, and that he was satisfied with the result. This information was obtained by re-examination of the patients at the Mayo Clinic (twenty cases), by adequate reply of the patients to a detailed questionnaire (forty-three cases), or by reports from the patients or their family physicians which contained sufficient details to make it possible to judge fairly the results of treatment (thirteen cases).

FIG. 4

FIG. 5

Fig. 4: Anteroposterior view of the right elbow joint of a patient (Case 1) with tardy paralysis of the ulnar nerve. There was an old intra-articular fracture of the lateral condyle of the right humerus, with non-union of the fragment, which was displaced anteriorly.

Fig. 5, *a:* Left hand of a patient (Case 6) who had tardy paralysis of the ulnar nerve. Shows effects of atrophy of the intrinsic muscles of the hand.

Fig. 5, *b:* Lateral view shows moderate hypertrophic arthritis of the elbow joint, with spur formation.

Thirty-seven patients who obtained satisfactory results had residual symptoms which consisted chiefly of anaesthesia and paraesthesia. A few patients had some degree of pain, atrophy, or weakness. None of these symptoms were severe; all of them occurred intermittently and were precipitated by fatigue, arising from heavy work.

Six patients were not benefited by surgical treatment. One of these patients was treated by subcutaneous anterior transplantation of the nerve, and another underwent excision of a neuroma and end-to-end anastomosis of the ulnar nerve, in addition to intramuscular anterior transplantation of the nerve.

No information was available in twenty-four cases.

REPORT OF CASES

Case 1. A housewife, forty-two years old, had sustained a fall and had suffered a fracture of the right elbow joint fourteen years prior to the onset of ulnar palsy. The extremity had been immobilized in acute flexion, and the patient had not regained full use of her arm for more than a year. Fourteen years after the accident, she had begun to experience paraesthesia and numbness over the distribution of the ulnar nerve in her right hand. This condition had progressed slowly, and her household activities had had to be seriously curtailed. On examination, she exhibited complete ulnar paralysis on the right. A roentgenogram of the right elbow disclosed an old intra-articular fracture of the lateral condyle of the right humerus with non-union of the fragment, which was displaced anteriorly (Fig. 4). On June 22, 1937, one of the authors (J. G. L.) explored the region of the right medial epicondyle, while the patient was under the influence of ether, administered by the open-drop method. A large neuroma of the ulnar nerve was discovered, posterior to the medial epicondyle. Neurolysis of the neuroma was done, and the release of tension caused the contents within the neural sheath to bulge between the edges of the incisions. The nerve was transplanted anteriorly in a muscle bed. The patient reported complete return of function of the hand and no residual symptoms, two years after the operation.

Case 2. A housewife, thirty-eight years old, had been injured in a serious automobile accident. Among other injuries, she had suffered a fracture of the left olecranon process of the ulna, which had been treated by open reduction. When she was examined, five months after the accident, there had been no evidence of a peripheral-nerve lesion; roentgenograms had showed the fragments to be in excellent position; and the patient was attaining good return of elbow motion. However, three months later she had had limitation of motion of the elbow joint, and callus had obliterated the ulnar groove. Slight weakness of muscles supplied by the ulnar nerve had been noted, but no sensory impairment. It was thought advisable to transplant the ulnar nerve without delay, to avoid further destruction of nerve function. On August 14, 1934, one of the authors (J. G. L.) performed an anterior intramuscular transplantation of the ulnar nerve; the patient was given ether, administered by the open-drop method. The ulnar groove was found to be obliterated by callus and fibrous tissue, but a neuroma was not present. At the same operation the elbow joint was manipulated. Inquiry, twelve years after the operation, disclosed that the patient had obtained an excellent result, and had no residual symptoms.

Case 3. A farmer, forty-five years old, had had a gonococcal type of arthritis of the right elbow, and for more than twenty years afterward had had pain and limitation of motion in that joint. Eight months before the patient's admission, numbness had developed in the ulnar half of the right hand; and four months later he had noticed wasting and weakness of the same hand. On examination, motor and sensory findings were typical of paralysis of the ulnar nerve. Roentgenograms of the elbow disclosed hypertrophic arthritis, with multiple loose osteocartilaginous bodies. On August 18, 1933, the medial aspect of the elbow joint was explored; the patient was given ether, administered by the open-drop method. The ulnar nerve was flattened, fibrotic, and under considerable tension, because of partial obliteration of the ulnar groove by the arthritic process. No neuroma was present. The nerve was elevated and then transplanted anteriorly into a muscle bed. Thirteen years later, the patient was working as a carpenter; he had no symptoms of paralysis of the ulnar nerve.

Case 4. In a forty-year-old farmer, typical ulnar palsy developed insidiously on the right, over a period of about four years. About a year previous to the patient's admission, scalenotomy had been performed elsewhere, without benefit. The patient had habitually driven a tractor, resting one or the other of his elbows on a fender; this had subjected his elbow to repeated traumata. There was no history of other injuries to the elbow or of disease. Roentgenograms of the thorax and of the cervical portion of the spinal column showed no evidence of a cervical rib; and results of manoeuvres designed to demonstrate the scalenus anterior syndrome were negative. Both ulnar nerves were enlarged at the elbow; the right ulnar nerve was the larger.

Neurological signs and symptoms of paralysis of the ulnar nerve were present only on the right side. One of the authors (J. G. L.), on August 31, 1944, explored the right ulnar nerve at the elbow and found a fusiform neuroma of the nerve in the ulnar groove. Neurolysis of the neuroma was performed, and the nerve was transplanted into a muscle bed anterior to the medial epicondyle of the humerus. Brachial-plexus regional anaesthesia was employed for this procedure. The patient's right hand improved steadily after the operation. About a year later, however, identical signs and symptoms developed in the left arm. On February 18, 1946, the same operative procedures were carried out on the left side. The patient obtained an excellent return of function in the right hand. He could not be located so that we might inquire as to return of function of the left hand.

CASE 5. A fifty-year-old clergyman had had sensitivity of the right ulnar nerve since childhood. In his brother, who had a similar condition, atrophy and weakness of one hand had developed recently. After throwing a baseball or when resting on his elbow, the patient had always experienced tenderness in the region of the ulnar groove, and numbness and tingling in the hand. His symptoms always had been worse on the right. His occupation required incessant reading; he had habitually rested his right elbow on the arm of a chair. On examination, the ulnar grooves were found to be abnormally shallow bilaterally. The right ulnar nerve was enlarged and tender. There was motor paralysis of the muscles supplied by the ulnar nerve on the right side, but sensation was normal. On December 31, 1936, the medial aspect of the right elbow was explored, with the patient under the influence of regional anaesthesia of the brachial plexus. The ulnar groove was abnormally shallow on a developmental basis. The nerve was enlarged and fibrotic, but neuroma was not present. Ten years later, the patient reported that his only residual symptom was slight numbness of the ulnar side of the hand when he became fatigued from long, hard drives in his automobile. He was well satisfied with the results of the operation; no difficulty had developed on the left side.

CASE 6. A farmer, seventy-one years old, had injured his right elbow at the age of twenty-five years. He had had a stiff elbow after the accident, but signs and symptoms of ulnar paralysis had not developed until ten months before his admission. Roentgenograms of the right elbow demonstrated extensive hypertrophic arthritis. At operation on May 7, 1930, the ulnar nerve was found to be firmly embedded in scar tissue behind the medial epicondyle. Anterior intramuscular transplantation of the nerve and neurolysis of the neuroma were performed. The patient regained normal function of the right hand, but three years later he returned with evidence of paralysis of the left ulnar nerve (Fig. 5, *a*). Roentgenograms showed moderate hypertrophic arthritis of the left elbow joint, with spur formation (Fig. 5, *b*). On August 29, 1933, a similar operative procedure was carried out on the left side; extensive adhesions and scar tissue were found to have accounted for the condition. The patient was re-examined two years after the last operation. At that time he had slight atrophy and weakness of the ulnar-supplied muscles on the left, but both arms had been restored to usefulness.

CASE 7. Paralysis of the left ulnar nerve had developed in a restaurant owner, fifty-seven years old, over a two-year period prior to his admission. In addition to typical paralysis of this nerve, physical examination disclosed a palpable mobile mass in the left ulnar groove. Roentgenograms of the elbow demonstrated nothing abnormal. Clinically, the mass was thought to be a neuroma of the ulnar nerve. On November 27, 1945, surgical exploration of the region about the left elbow disclosed a multilocular ganglion cyst, about two centimeters in diameter, which arose from an adjacent tendon and was compressing the ulnar nerve. This cyst (Fig. 3) was completely removed; but transplantation of the nerve was not performed, since the elbow joint appeared to be normal otherwise. Six months later the patient reported satisfactory return of normal function in his left hand.

CASE 8. An automobile mechanic, twenty-eight years old, suffered from progressive paralysis of the right ulnar nerve, which had followed an injury to his elbow. On physical examination he was found to have impairment of function of the ulnar nerve and a large, cystic, tender mass above the medial condyle on the right. Subcutaneous transplantation of the nerve had been performed elsewhere, but the patient had not obtained relief from pain and tenderness in the region of the elbow. His discomfort was severe enough to necessitate large doses of narcotic agents, and he was rapidly becoming addicted to them. Roentgenograms of the right elbow demonstrated nothing abnormal. Clinically, the mass was suspected of being a ganglion cyst. On August 13, 1943, surgical exploration of the ulnar nerve showed that the mass was a large fibrous neuroma of the ulnar nerve, measuring four by one by one centimeters (Figs. 2-A and 2-B). The neuroma was of such size that it was necessary to remove it and perform end-to-end anastomosis of the nerve in order to mobilize the nerve and transplant it into an intramuscular bed. Three years after the operation the patient was gainfully employed as an automobile mechanic, but he was dissaissfied with the result. He had residual paraesthesia and pain over the distribution of the ulnar nerve on the right, and a tender mass had recurred near the elbow.

CASE 9. A physician, twenty-eight years old, had suffered a fracture of the right elbow at fifteen years of age, which had been treated by the closed method of reduction. An increased carrying-angle type of deformity of the right elbow had developed on the basis of an ununited fracture of the lateral condyle of the humerus. Symptoms of a right ulnar-nerve palsy had commenced, five years later. The patient had undergone anterior subcutaneous transplantation of the ulnar nerve three times without success; these procedures had been done elsewhere. He also had received one extensive course of deep roentgen-ray therapy, elsewhere. The operations and the roentgen-ray therapy had provided only temporary relief from pain, and had not altered the progress of the atrophy and anaesthesia in his hand. His disability was of such severity that he was faced with the decision of giving up his chosen field of surgery or even of abandoning the practice of medicine. On May 11, 1938, the right ulnar nerve, which was found in subcutaneous tissues anterior to the medial epicondyle, was explored surgically. There was a fusiform enlargement of the nerve, six centimeters in length. Neurolysis of the neuroma was performed, and the nerve was transferred medially into a muscle bed. The patient was advised to continue his surgical training and to attempt surgical practice. Eight years later, this patient was a successful surgeon, who experienced only occasional slight numbness and tingling in his right hand after a strenuous working day.

CASE 10. A public accountant, sixty-three years old, was found, during an examination for unrelated conditions, to suffer from partial paralysis of the right ulnar nerve. There was no history of disease or injury of the elbow. However, the patient habitually rested his right elbow on a desk in his work as an accountant. He had complete motor paralysis of the ulnar nerve, and the right ulnar nerve was enlarged at the elbow. There was no evidence of sensory disturbance. Conservative treatment was advised. He was instructed to avoid resting his elbow in such a way as to injure the ulnar nerve, and a series of exercises were prescribed to maintain tone in the muscles supplied by this nerve. More than a year later the patient reported that his hand was functioning normally and that the atrophy was disappearing. Whereas he had not been able to button his clothes, shave himself, or write satisfactorily at the time he was examined, he could do all these things at the time he was dismissed.

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FLOOR PAD FOR FOOT-EXERCISING

BY MAURICE H. HERZMARK, M.D., WASHINGTON, D. C.

Most cases of flat-foot or of weak foot can be prevented. Often the cause of flat-foot is a flat walking surface, and the condition can be prevented by an irregular surface. The arch of the human foot is supported by muscles, attached to the bones and ligaments. It has been developed, by a process of evolution, to adapt the foot to swift and easy movement over rough and irregular ground. The spring-like arch takes up the shock of the impact and reduces the surface of contact. Rough, pebbly ground, hot sandy soil, or cold, soggy marshland would be hard to negotiate on flat, splayed feet. In primitive times, when man hunted and was hunted, life depended upon well-developed nimble feet. His soil determined the kind of feet he would have. The rougher the ground, the better his feet. Now, with well-paved sidewalks, polished floors, and smoothly rolled lawns, the feet that tread this smooth terrain do not develop spring and strength.

The infant who learns to walk on irregular and springy surfaces will build up the muscles of his feet and legs, which support the arches. By the time he has outgrown his play-pen days, his feet are strong; and walking habits have been developed which will keep his feet in the proper weight-bearing position.

FIG. 1

FIG. 2

Fig. 1: Note pronated feet, when child stands on flat surface.
Fig. 2: Child stands on a pad designed to exercise the feet (note knobs). Improved position of feet can be seen.

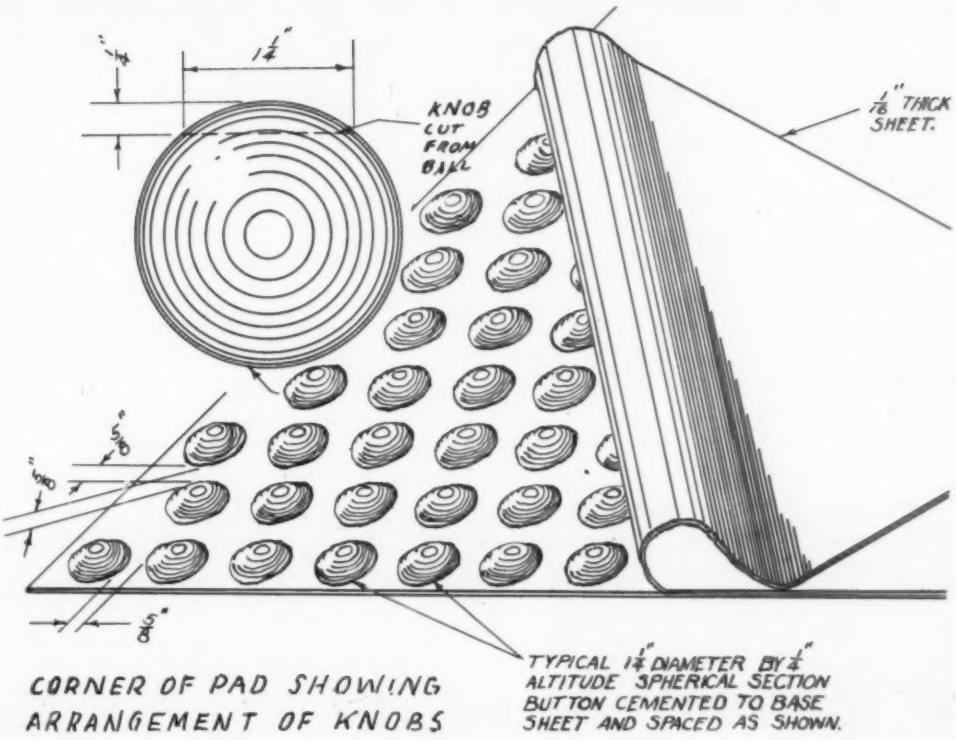
1¼"
KNOB CUT FROM BALL
1/16" THICK SHEET.
5/8"
5/8"
CORNER OF PAD SHOWING ARRANGEMENT OF KNOBS
TYPICAL 1¼" DIAMETER BY ¼" ALTITUDE SPHERICAL SECTION BUTTON CEMENTED TO BASE SHEET AND SPACED AS SHOWN.

FIG. 3

Construction of rubber pad.

For a number of years it has been the author's practice to suggest that the play pen of a child learning to walk be fitted with a pad of irregular tufted material, so that the walking surface will rock the feet. The development of the feet in these children was such that none of them needed corrective shoes, arch supports, or other aids to proper weight-bearing.

Recently a very effective pad has been constructed from sponge-rubber sheeting, with segments of sponge-rubber balls cemented on (Fig. 3). Sheeting, one-sixteenth of an inch thick and forty by forty inches in size, to fit the floor of an ordinary play pen, was used. The balls were the type sold for the use of children. The segments were cut by outlining on the surface of a ball, having a diameter of two and one-half inches, as many circles one and one-quarter inches in diameter as possible. These segments were cut with a sharp straight knife, dipped in water. About eight segments with a flat bottom and curved top, one-quarter inch high, can be obtained from each ball. About 625 segments are cemented in staggered arrangement, with the curved surface against the sheet of sponge rubber. The pad is placed with the segments against the floor of the pen. This leaves the walking surface smooth in appearance, but the curved knobs under the pad rock the feet and prevent them from pronating or being used passively. This pad has the following advantages: It is soft and springy, yet has a smooth surface; it will not hurt the infant if he falls; it is sanitary; and the knobs are of the proper size and position to fit an infant's foot.

Experience over a period of fifteen years has shown that this method of automatically exercising the infant's feet will forestall flat or weak feet in later life.

SLOTTED JAW FORCEPS FOR BONE-PLATING

BY S. PERRY ROGERS, M.D., EL PASO, TEXAS

The customary surgical technique in plating fractures of the long bones includes the use of bone-holding forceps, generally in pairs, to grasp both fragments and to manipulate them into reposition, after which one forceps is usually sufficient to maintain the reduction. The awkward stage of the procedure frequently has been the application of the plate. Often this has entailed loosening the forceps, losing the reduction, remanipulating the fragments, and juggling the forceps so as to get the plate beneath the forceps and properly placed across the reduced fracture. The alternate procedure has been to attach the plate to one unreduced fragment, and to hope that it will lie properly on the other fragment after reduction.

FIG. 1

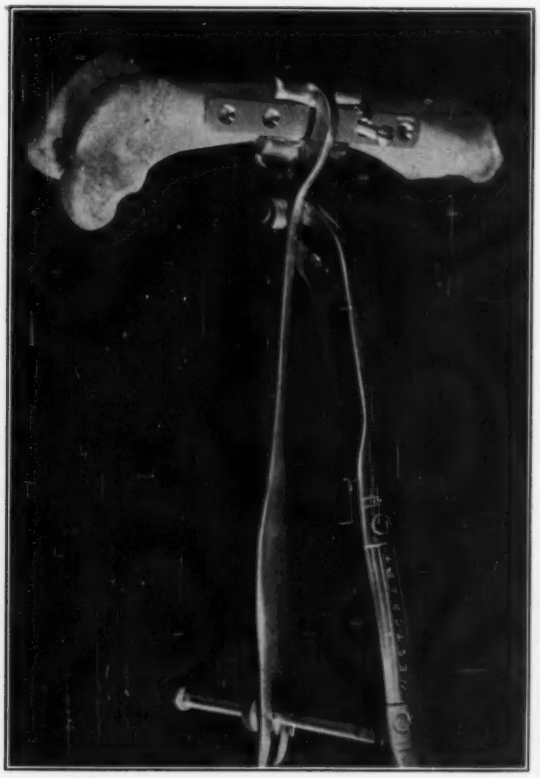

FIG. 2

Provision of a slot of appropriate width and depth in the upper jaw of the holding forceps allows the introduction and attachment of the plate without disturbance of the reduction. In the instrument illustrated (Fig. 1), the upper (working) jaw faces the handles at an angle of 45 degrees, to facilitate access with minimum exposure. The grasping surfaces on each side of the slot are long enough to overlie a considerable amount of comminution, while the under jaw is sufficiently thin and narrow to allow its introduction with minimum stripping. A standard slip joint at the hub permits adjustment to any size of bone from a clavicle to a femur (Fig. 2). A standard locking device is incorporated in the handles.

News Notes

The Fifteenth Annual Convention of **The American Academy of Orthopaedic Surgeons** will be held at the Palmer House, Chicago, January 24 through 29, 1948, under the presidency of Dr. Rex L. Diveley. A program of unusual interest has been prepared. Registration will begin Saturday morning, January 24. The Audio-Visual Program will be presented Saturday afternoon and Sunday morning, to be followed by the Instructional Courses on Sunday afternoon and Monday morning. The Scientific Program will begin on Monday afternoon and close at noon Thursday. Four distinguished foreign guests are expected to participate in the program. A preliminary program containing information concerning this meeting will be mailed to all members before the holidays.

Applications for Part I of the examination of **The American Board of Orthopaedic Surgery** must be received by the Secretary, Dr. Francis M. McKeever, 1136 West 6th Street, Los Angeles 14, California, *not later than* January 15, 1948.

The Annual Convention of **The National Society for Crippled Children and Adults, Inc.,** will be held at the LaSalle Hotel, Chicago, November 3 to 5, 1947. The program for Monday will be developed around the Convention theme "The Handicapped—a Great National Resource"; the Tuesday program will concern Rehabilitation; and the Wednesday program will be on Cerebral Palsy. All interested persons are cordially invited to attend the Convention.

The Annual Meeting of the **American Occupational Therapy Association** will be held at Hotel del Coronado, Coronado, California, November 2 to 7, 1947.

The American Academy of Allergy will hold its annual convention at Hotel Jefferson, St. Louis, Missouri, December 15 to 17, inclusive. All physicians interested in allergy problems are cordially invited to attend the sessions as guests of the Academy by registering, without payment of fee. The program and the scientific and technical exhibits have been arranged to cover a wide variety of conditions where allergic factors may be important. Advance copies of the program may be obtained by writing to the Chairman on Arrangements, Charles H. Eyermann, M.D., 634 North Grand Boulevard, St. Louis, Missouri.

The Annual Report of **The National Foundation for Infantile Paralysis** for the fiscal year ending May 31, 1947, has recently appeared. This report contains a valuable summary of the tremendous activities of the Foundation during this period, which was marked by severe epidemics of infantile paralysis.

The **Baruch Committee on Physical Medicine** has recently issued a report covering the period of April 1, 1945, to December 31, 1946. The report emphasizes the significant advance in physical medicine and rehabilitation during this period, and mentions in detail the work at various centers, which has been made possible by grants from the Research Fund.

Through **The John and Mary R. Markle Foundation,** scholarships are now being made available to young men and women, graduates of accredited medical schools in the United States and Canada, who contemplate careers of research and teaching in the sciences basic to medicine. The liberal "post-fellowship" grants are being made to candidates recommended by their medical schools.

Announcement has been made by the Mellon Institute of Pittsburgh of the establishment of research fellowships on orthopaedic appliances by the **Sarah Mellon Scaife Foundation.** The program of study will be carried out under the direction of the Department of Orthopaedic Surgery of the School of Medicine, University of Pittsburgh.

An interesting meeting of **German orthopaedic surgeons** was held at the *Universitätsklinik* in Heidelberg, on September 3, 4, and 5. The committee in charge of the congress included Prof. Weil of Heidelberg, Prof. Max Lange of Bad Tölz, and Prof. Hohmann of Munich.

At the opening session, Prof. Weil greeted the guests; Prof. Hohmann gave the introductory address;

and Prof. Lange opened the scientific part of the congress, outlining the program which had been prepared.

The main topics discussed were:

The problem of providing for the care and rehabilitation of amputees.

The importance of the herniated nucleus pulposus as a cause of lumbago and sciatica.

New methods of treatment of bone and joint tuberculosis.

The operations for irreparable paralyses, following impairment of the peripheral nerves, resulting from accidental injuries; the indications for their use and the results which may be expected.

The treatment of flail joints after extensive joint resection.

Operative nailing of the hip joint in chronic disease.

There were several speakers on each of these general topics, with others presenting papers on related subjects, and general discussion following the formal presentation of papers.

The last two sessions featured a series of short presentations.

During the coming weeks, the **Committee on Postgraduate Training in Orthopaedic Surgery,** in association with the Council on Medical Education and Hospitals of the American Medical Association and The American Board of Orthopaedic Surgery, will conduct a survey of the orthopaedic-training services in the United States. Two hundred and forty-three hospitals will be visited by twenty-nine orthopaedic surgeons.

Information will be obtained from these hospitals on the clinical and basic-science training which the orthopaedic residents are receiving. There are at the present time approximately 550 doctors in training on approved orthopaedic residencies.

This survey will be completed by December 1, following which the reports will be reviewed by the Committee and recommendations made accordingly to the Board and Council.

A. R. Shands, Jr., M.D., Secretary

AMERICAN SOCIETY FOR SURGERY OF THE HAND

The American Society for Surgery of the Hand will meet in Chicago on January 23 and 24, 1948, in conjunction with The American Academy of Orthopaedic Surgeons. Visitors are welcome to the scientific session. The preliminary program is as follows:

Volkmann's Ischaemic Contracture, Local in the Hand.
Sterling Bunnell, M.D., San Francisco, California.

Tendon Grafts as a Substitute for Flexor Tendons.
Sumner L. Koch, M.D., Chicago, Illinois.

Tendon Transfers and Arthrodeses in Combined Median and Ulnar Nerve Paralysis.
J. William Littler, M.D., New York, N. Y.

Initial Treatment of Hand Injuries: Some Common Errors.
Condict W. Cutler, M.D., New York, N. Y.

Transplantation of Metatarsals to the Hand to Replace the Metacarpal.
Walter C. Graham, M.D., Santa Barbara, California;
Captain Daniel Riordan, M.C., Phoenixville, Pennsylvania (by invitation).

Metacarpal Transfer for Improving the Function of the Crippled Hand.
Lt. Colonel Gilbert L. Hyroop, M.C., Battle Creek, Michigan.

Tenosynovitis of the Extensor Carpi Ulnaris Tendon Sheath.
Clarence A. Luckey, M.D., Oakland, California.

Experimental Study of Cellophane in Prevention of Adhesions after Tendon Suture.
William H. Requarth, M.D., Chicago, Illinois.

Z-Plasty *versus* Free Skin Graft for Correction of Volar Skin Contractures of the Hand.
William H. Frackelton, M.D., Milwaukee, Wisconsin.

Tumors of the Hand.
Michael L. Mason, M.D., Chicago, Illinois.

Mobilization of Stiff Finger Joints.
S. Benjamin Fowler, M.D., Nashville, Tennessee.

Report of the Committee on Rehabilitation.
Donald B. Slocum, M.D., Eugene, Oregon.

Opponens Transplant.
John W. Kirklin, M.D., Rochester, Minnesota (by invitation).

Sympathetic Surgery for Lesions of the Upper Extremity.
C. Hunter Sheldon, M.D., Pasadena, California (by invitation).

Presentation of Cases.
Sumner L. Koch, M.D., Chicago, Illinois;
Michael L. Mason, M.D., Chicago, Illinois;
Harvey S. Allen, M.D., Chicago, Illinois.

THE AMERICAN ORTHOPAEDIC ASSOCIATION

The Sixtieth Annual Meeting of The American Orthopaedic Association, under the presidency of Dr. LeRoy C. Abbott, was held at The Homestead, Hot Springs, Virginia, June 27, 28, 29, and 30, 1947. An excellent program had been prepared by the Program Committee and the standard of the papers from both guests and members was unusually high.

The program follows:

Friday, June 27

Morning Session

The Primary Suturing of Compound Fractures Including Immediate Internal Fixation, Skin Graft, and Compression Dressings.
Arthur G. Davis, M.D., Erie, Pennsylvania.
Discussion: H. Earle Conwell, M.D., Birmingham, Alabama;
Kellogg Speed, M.D., Chicago, Illinois.

The Management of Venous Thrombosis of the Extremities.
Daniel C. Elkin, M.D., Emory University, Georgia (by invitation).

Follow-up Report on a New Surgical Procedure for Lymphoedema of the Extremities.
H. B. Macey, M.D., Temple, Texas.
Discussion: Ralph K. Ghormley, M.D., Rochester, Minnesota;
Daniel C. Elkin, M.D., Emory University, Georgia (by invitation).

Bone Marrow and Blood Studies in Multiple Myeloma and Certain Other Skeletal Lesions.
Ernest H. Falconer, M.D., San Francisco, California (by invitation).

Bone and Joint Changes in Hemophilia.
Ralph K. Ghormley, M.D., Rochester, Minnesota;
Reed S. Clegg, M.D., Rochester, Minnesota (by invitation).
Discussion: William T. Green, M.D., Boston, Massachusetts;
Guy A. Caldwell, M.D., New Orleans, Louisiana.

Internal Fixation for Lumbosacral Fusion.
Donald King, M.D., San Francisco, California.
Discussion: Lenox D. Baker, M.D., Durham, North Carolina;
Alan DeForest Smith, M.D., New York, N. Y.

Operation to Correct the Valgus Deformity Resulting from Pott's Fracture.
E. B. Mumford, M.D., Indianapolis, Indiana.
Discussion: Frederick C. Kidner, M.D., Detroit, Michigan;
H. Earle Conwell, M.D., Birmingham, Alabama.

Afternoon Session

The Painful Shoulder—Observations on the Role of the Tendon of the Long Head of the Biceps Brachii in its Causation.
Harold H. Hitchcock, M.D., Oakland, California;
Charles O. Bechtol, M.D., Oakland, California (by invitation).
Discussion: J. Albert Key, M.D., St. Louis, Missouri;
Robert W. Johnson, M.D., Baltimore, Maryland.

A Preliminary Report on the Evaluation of Modifications of the Bankart Procedure for Recurrent Dislocations of the Shoulder Joint.
Joseph B. Josephson, M.D., San Jose, California (by invitation);
Jesse T. Nicholson, M.D., Philadelphia, Pennsylvania.
Discussion: Frederic C. Bost, M.D., San Francisco, California;
Toufick Nicola, M.D., Montclair, New Jersey.

Extraskeletal Ossifications Simulating Sarcoma.
Howard Hatcher, M.D., Chicago, Illinois.
Discussion: Allen F. Voshell, M.D., Baltimore, Maryland;
Samuel Kleinberg, M.D., New York, N. Y.;
Dallas B. Phemister, M.D., Chicago, Illinois.

New Method for Fusion of Ununited Fractures of the Carpal Bones.
Paul B. Steele, M.D., Pittsburgh, Pennsylvania.

Discussion: Edwin F. Cave, M.D., Boston, Massachusetts;
Arthur B. LeMesurier, M.B., Toronto, Ontario, Canada.

The Cineplastic Method in Upper-Extremity Amputations.
Rufus H. Alldredge, M.D., New Orleans, Louisiana.
Discussion: Paul B. Magnuson, M.D., Chicago, Illinois;
Philip D. Wilson, M.D., New York, N. Y.;
Verne T. Inman, M.D., San Francisco, California.

Pseudarthrosis in the Lumbosacral Spine.
Mather Cleveland, M.D., New York, N. Y.;
David M. Bosworth, M.D., New York, N. Y.;
Frederick R. Thompson, M.D., New York, N. Y. (by invitation).
Discussion: Joseph S. Barr, M.D., Boston, Massachusetts;
Eugene M. Regen, M.D., Nashville, Tennessee;
Alan DeForest Smith, M.D., New York, N. Y.

SATURDAY, JUNE 28

Morning Session

The Management of Comminuted Fractures of the Distal End of the Humerus Involving the Elbow Joint.
John L. McDonald, M.D., Toronto, Ontario, Canada.
Discussion: Walter P. Blount, M.D., Milwaukee, Wisconsin;
Walter G. Stuck, M.D., San Antonio, Texas.

Fractures of the Capitellum Humeri.
John C. Wilson, M.D., Los Angeles, California.
Discussion: Edwin W. Ryerson, M.D., Chicago, Illinois;
T. Campbell Thompson, M.D., New York, N. Y.;
J. S. Speed, M.D., Memphis, Tennessee.

Homografts in Orthopaedic Surgery.
Myron O. Henry, M.D., Minneapolis, Minnesota.
Discussion: Rufus H. Alldredge, M.D., New Orleans, Louisiana;
J. S. Speed, M.D., Memphis, Tennessee;
Alberto Inclan, M.D., Havana, Cuba;
Alan DeForest Smith, M.D., New York, N. Y.

Cartilaginous Cup Arthroplasty in Ununited Fractures of the Neck of the Femur.
John R. Moore, M.D., Philadelphia, Pennsylvania.
Discussion: Joseph A. Freiberg, M.D., Cincinnati, Ohio;
Paul C. Colonna, M.D., Philadelphia, Pennsylvania.

Surgical Treatment of Intractable Plantar Warts.
James A. Dickson, M.D., Cleveland, Ohio.
Discussion: R. Plato Schwartz, M.D., Rochester, N. Y.;
James E. M. Thomson, M.D., Lincoln, Nebraska;
A. W. Farmer, M.D., Toronto, Ontario, Canada.

An Evaluation of Penicillin Therapy in Acute Hematogenous Osteomyelitis.
W. A. Altemeier, M.D., Cincinnati, Ohio (by invitation).

Acute Hematogenous Osteomyelitis. A Study on Treatment.
I. William Nachlas, M.D., Baltimore, Maryland;
Herbert R. Markheim, M.D., Baltimore, Maryland (by invitation).
Discussion: Dallas B. Phemister, M.D., Chicago, Illinois;
Frank D. Dickson, M.D., Kansas City, Missouri;
A. W. Farmer, M.D., Toronto, Ontario, Canada.

SUNDAY, JUNE 29

Morning Session

Certain Features of the Mechanics of the Hip Joint.
Verne T. Inman, M.D., San Francisco, California (by invitation);
J. B. deC. M. Saunders, M.B., San Francisco, California (by invitation).

Congenital Pseudarthrosis—Follow-up Study after Massive Bone-Grafting.
Harold B. Boyd, M.D., Memphis, Tennessee;
Kermit W. Fox, M.D., Memphis, Tennessee (by invitation).
Discussion: Halford Hallock, M.D., New York, N. Y.;
Rex Diveley, M.D., Kansas City, Missouri.

Muscular Torticollis.
Fremont A. Chandler, M.D., Chicago, Illinois.
Discussion: J. Hiram Kite, M.D., Atlanta, Georgia;
Robert V. Funsten, M.D., Charlottesville, Virginia.
The Nitrogen Content of Bone. A Laboratory Study.
L. J. Strabino, M.D., Wilmington, Delaware (by invitation);
L. E. Farr, M.D., Wilmington, Delaware (by invitation);
A. R. Shands, Jr., M.D., Wilmington, Delaware.
Discussion: Carl E. Badgley, M.D., Ann Arbor, Michigan;
William T. Green, M.D., Boston, Massachusetts.
Presidential Address.
LeRoy C. Abbott, M.D., San Francisco, California.
Experimental Intervertebral-Disc Lesions.
J. Albert Key, M.D., St. Louis, Missouri;
Lee T. Ford, M.D., St. Louis, Missouri (by invitation).
Discussion: Edward L. Compere, M.D., Chicago, Illinois;
Joseph S. Barr, M.D., Boston, Massachusetts.
Overlap Bone Operation for Serious Malunions and Persistent Non-Unions of Fractures of Both Bones of the Forearm.
J. Warren White, M.D., Greenville, South Carolina.
Discussion: Robert D. Schrock, M.D., Omaha, Nebraska;
Robert W. Johnson, M.D., Baltimore, Maryland.

MONDAY, JUNE 30

Morning Session

Symposium on Congenital Dislocation of the Hip.
Alan DeForest Smith, M.D., New York, N. Y., *Chairman.*
Embryology of the Hip with Etiology and Pathology of Congenital Dislocation.
Carl E. Badgley, M.D., Ann Arbor, Michigan.
Results of Treatment of Congenital Dislocation of the Hip in Infancy.
Frederic C. Bost, M.D., San Francisco, California;
Helen Hagey, M.D., San Francisco, California (by invitation);
Edwin R. Schottstaedt, M.D., San Francisco, California (by invitation).
Results of Treatment of Posterior Congenital Dislocation of the Hip.
C. H. Crego, Jr., M.D., St. Louis, Missouri.
J. R. Schwartzmann, M.D., St. Louis, Missouri (by invitation).
Results of Treatment of Congenital Dislocation of the Hip.
Wallace H. Cole, M.D., St. Paul, Minnesota.
Late End-Result Studies of Treatment of Congenital Dislocation of the Hip.
A. Bruce Gill, M.D., Philadelphia, Pennsylvania.
Follow-up Studies and Additional Observations in Primary Anterior Congenital Dislocation of the Hip.
H. R. McCarroll, M.D., St. Louis, Missouri.
Congenital Dislocation of the Hip with Treatment in Older Age Group.
H. R. McCarroll, M.D., St. Louis, Missouri.
Report of Results of Treatment of Congenital Dislocation of the Hip by Osteotomy.
Herman C. Schumm, M.D., Milwaukee, Wisconsin.
Report of Results of Treatment of Irreducible Congenital Dislocation of the Hip by Arthrodesis.
Charles J. Frankel, M.D., Charlottesville, Virginia (by invitation).
Report of Results of Treatment of Congenital Dislocation of the Hip by Vitallium-Mold Arthroplasty.
M. N. Smith-Petersen, M.D., Boston, Massachusetts.
Discussion: George K. Coonse, M.D., Boston, Massachusetts;
Leo S. Lucas, M.D., Portland, Oregon;
Charles O. Bechtol, M.D., Oakland, California (by invitation);
Beckett Howorth, M.D., New York, N. Y.;
Edward L. Compere, M.D., Chicago, Illinois;
Carl E. Badgley, M.D., Ann Arbor, Michigan;
Joseph A. Freiberg, M.D., Cincinnati, Ohio.

Executive Sessions were held at noon on Saturday, June 28, and Monday, June 30. The Annual Association Banquet was given on Saturday evening, June 28.

Robert I. Harris, M.B., Toronto, Ontario, Canada, is President of The Association for the year 1947–1948.

At the last Executive Session, the following officers, members of committees, and delegates were elected:

Officers

President-Elect: Ralph K. Ghormley, M.D., Rochester, Minnesota;
Vice-President: Alberto Inclan, M.D., Havana, Cuba;
Secretary: C. Leslie Mitchell, M.D., Detroit, Michigan;
Treasurer: Frank D. Dickson, M.D., Kansas City, Missouri.

Committee Members

Membership Committee: Wallace H. Cole, M.D., St. Paul, Minnesota;
Program Committee: Joseph A. Freiberg, M.D., Cincinnati, Ohio;
Research Committee: I. William Nachlas, M.D., Baltimore, Maryland.

Delegate to the American College of Surgeons: Kellogg Speed, M.D., Chicago, Illinois.

Representatives on The American Board of Orthopaedic Surgery:

H. Earle Conwell, M.D., Birmingham, Alabama;
Arthur G. Davis, M.D., Erie, Pennsylvania.

The following were elected to active membership in The Association:

George Carpenter, M.D., Nashville, Tennessee;
Verne T. Inman, M.D., San Francisco, California;
R. B. Raney, M.D., Durham, North Carolina;
Clay Ray Murray, M.D., New York, N. Y. (posthumously).

ACKNOWLEDGMENTS

The Journal wishes to acknowledge receipt of the following publications, which have been sent to the Editorial Department:

Anales (Valencia, Spain), **2:** Núm. 1, 1947.
Arquivos do Instituto de Biologia do Exército (Rio de Janeiro), **7:** Núm. 7, 1946.
Baruch Committee on Physical Medicine (New York, N. Y.), Annual Report.
Boletin de la Asociation Médica de Santiago (Santiago, R. D.), **4:** No. 4, 1946; **5:** No. 1, 1947.
Boletin del Colegio Médico de la Habana (Cuba), **10:** Núms. 2, 3, y 4, 1947.
Boletin del Instituto de Pathología Médica (Madrid), **2:** Núm. 6, 1947.
Boletines de la Sociedad de Cirugía de Rosario (Argentina), **14:** Nos. 2 y 3, 1947.
Brasil Médico-Cirúrgico (Rio de Janeiro), **8:** Nos. 5–6, 1946.
The Bulletin of the U. S. Army Medical Department (Washington, D. C.), **7:** Nos. 4 to 9, 1947.
Endogeneous Endocrinotherapy Including the Causal Cure of Cancer. Compendium by Dr. Jules Samuels. Amsterdam, Holdert and Co., 1947.
Evaporated Milk Association (Chicago, Illinois), "Infant Feeding with Evaporated Milk".
Hospital de Nuestra Señora de Guadalupe (México, D. F.), Tepeyac, A. C.
Hospital for Joint Diseases (New York, N. Y.), Annual Report, 1946; Bulletin, **8:** No. 1, 1947.
The Johns Hopkins University Circular (Baltimore, Maryland), No. 5, May 1947.
Médica (Matanzas, Cuba), **6:** Núms. 3 y 4, 1947.
The National Foundation for Infantile Paralysis (New York, N. Y.), Annual Report, 1947.
Osteotomy of the Finger. A Case Report. By Hampar Kelikian, M.D. Reprinted from Quart. Bull., **21:** 111, 1947.
The Physiotherapy Review (New York, N. Y.), **27:** No. 4, 1947.
Revista Médica Municipal (Rio de Janeiro), **9:** Núm. 2, 1946; **10:** Núm. 1, 1947.
Sanidad y Beneficencia Municipal (Habana, Cuba), **6:** Núm. 1, 1946; **7:** Núm. 1, 1947.
United States Department of Labor (Washington, D. C.), "Migrant Labor", 1947.
United States Public Health Service (Washington, D. C.), The Journal of Venereal Disease Information, **28:** Nos. 7, 8, and 9, 1947; Public Health Reports, **62:** Nos. 27 to 39, 1947; Supplement No. 195.

CLAY RAY MURRAY
1890–1947

In June of this year, Clay Ray Murray was elected posthumously to The American Orthopaedic Association. There could have been no more suitable and appropriate expression of the respect and affection in which he was held by orthopaedic surgeons.

He died on June 14, 1947.

Native of New York City, he was graduated from the College of Physicians and Surgeons in 1912. There followed four years of internship at the New York Hospital and several years of service abroad in the Army Medical Corps. In 1921 he joined the Surgical Staff of the New York Hospital, and later that of the Lincoln Hospital. At the time of its establishment in 1928, he was appointed Assistant Director of the Fracture Service of the Presbyterian Hospital and Associate Professor of Surgery at the College of Physicians and Surgeons. He became Chief of the Fracture Service and Professor of Orthopaedic Surgery in 1945.

Although his dominant surgical interest and the greater part of his life work were devoted to fractures, he became a thoroughgoing student of orthopaedic surgery. In the broader field, clinical experience, wide reading, and extensive travels, which made possible adequate visits at many of the leading clinics of the world, gave him an unusually rich background and high potential. He was very much interested in *The Journal*. One of his last professional duties was to serve as a representative of The American Academy of Orthopaedic Surgeons at the conference held in London, May 27, 1947, to formulate recommendations for the organization of British-American co-publication of *The Journal*.

His original contributions, including work on the healing process in bone following fracture, studies of the reaction of bone to various high-alloy metals, and developments in the technique of operative treatment of fractures, are valuable.

His intensity and enthusiasm kindled in his students a like flame; as a teacher he was successful. His hard-won convictions and graphic style made him a forceful speaker and writer.

Plagued by illness which seldom left him free of physical handicap, from the time of his internship, he never complained, he was never irritable. Instead, he retained an inexhaustible enthusiasm for orthopaedic surgery and an extraordinary capacity for accomplishment. Loyal, esteemed, mature in skill and judgment, a seemingly tireless worker, he will remain fixed in our memories even more for his deep and unfailing enthusiasm and his sheer courage.

BARNEY JAMES HEIN
1889–1947

Word has been received of the death of Barney J. Hein, on August 17, after a brief illness. Dr. Hein was born in Toledo, Ohio, and, except for three years of postgraduate work at Harvard Medical School and for service overseas in World War I, as Captain in the Army Medical Corps, he spent his life in Toledo. He received his medical degree from Toledo Medical College in 1912 and then served his internship at St. Vincent's Hospital.

He devoted a good deal of his time to industrial surgery, served on the staffs of the Flower Hospital, Mercy Hospital, Toledo Hospital, and Women's and Children's Hospital, and was Chief of the Orthopaedic Staff at St. Vincent's Hospital. He was also a member of a number of societies, including the American Medical Association and the Ohio State Medical Association, and was a fellow of the American College of Surgeons and The American Academy of Orthopaedic Surgeons.

In addition to his accomplishments in the field of orthopaedic surgery, Dr. Hein was active in Toledo civic organizations. He will be greatly missed by his associates and friends.

Current Literature

OSTEOTOMY OF THE LONG BONES. Henry Milch, M.D. Springfield, Illinois, Charles C. Thomas, 1947. $6.75.

If by philosophy is meant an attempt to think accurately about fundamental problems, then this volume by Henry Milch might well be titled, "The Philosophy of Osteotomy". Scarcely any topic in orthopaedic surgery is as hackneyed as osteotomy. It was one of the earliest orthopaedic operations. Hundreds of different methods have been devised and numerous articles have been published. To most of us it would seem that enough—possibly more than enough—had already been written, and yet in this book the author has given new points of view, has analyzed the accepted conventional procedures with refreshing originality, and thereby injected new life into what might otherwise have been a profitless field of orthopaedic thought.

The first part of the book is devoted to axial displacements which may occur in the long bones. These are divided into the lineal, torsional, transpositional, and angulational displacements. In his attempt to employ terms accurately, Milch rejects the accepted words "linear" and "longitudinal", and suggests "lineal" to describe the "axial displacement which occurs when an osteotomized fragment is moved either distally or proximally in the direction of its longitudinal axis". The term "torsional" is used rather than "rotational" to indicate an essential difference between the concept of *rotation*, which "connotes a change of the whole bone with respect to some external frame of reference", and *torsion*, which applies to a "change in the position of one part of the bone with respect to another part of the same bone". In discussing both the transpositional and angulational osteotomies, trigonometric formulae are used to substantiate the accuracy of the author's deductions.

The second part of the book deals chiefly with the "axial displacement of the femur which occurs in the coronal plane, and which has been called the abduction osteotomy". Here Milch's previous publications, describing the importance of the postosteotomy angle, are given due emphasis. His final chapter, "Resection of the Femoral Neck with Pelvic Support Osteotomy for Ankylosis of the Hip", is the logical outgrowth of a rich experience with the abduction osteotomy. Unquestionably, this operation will not find favor with the supporters of arthroplasty, but time alone can decide whether the Milch procedure may not eventually be considered the operation of choice when dealing with ankylosed arthritic hips.

Although Milch thinks essentially along mechanical lines, he is also alive to the biological implications of osteotomy. He shows a fine historical grasp and a thorough knowledge of the literature; yet he does not befog the issue with too many diverse opinions. Instead he seeks clarity by a vigorous expression of his own thinking.

It is only natural that such a book as this is not easy reading; many paragraphs have to be pondered like a problem in geometry. To the orthopaedic surgeon who is not afraid of intellectual exertion, however, this book will prove a stimulating guide and an incentive to more accurate orthopaedic surgery.

SURGERY OF THE HAND. Ed. 2. R. M. Handfield-Jones, M.C., M.S., F.R.C.S. Edinburgh, E. and S. Livingstone Ltd., 20 shillings; Baltimore, The Williams and Wilkins Company, 1946. $5.50.

No attempt is made in Handfield-Jones's second edition of *Surgery of the Hand* to present the entire subject in great detail, but rather to give the essentials of primary hand care to the general surgeon, who must deal with the early problems of injury and infection.

The 164 pages are divided into three sections, covering infections, injuries, and other surgical lesions. Over half of the text deals with the subject of infection. The essentials of Kanavel's teaching, coupled with the author's vast experience, make this major section an especially valuable one. Handfield-Jones stresses primarily functional restoration of the infected hand, and turns his treatment at all times toward this key objective. Differential diagnosis of infection is carefully covered, and the care of the infected hand is outlined lucidly. The author emphasizes repeatedly the need for absolute certainty of diagnosis prior to any incision for drainage. The use of hot fomentations is discouraged in favor of dry heat.

The section on injuries covers the principles of Watson-Jones in the handling of fractures and dislocations. A chapter on burns gives the experience gained through the Royal Air Force.

Primary suture of severed flexor tendons within sheaths is condemned by the author, in accord with Iselin.

A statement is made that preservation of the proximal phalanx of the middle or ring finger, or a portion thereof, and not the metacarpal head, is necessary in preventing a rotation of the outer adjacent finger. Other authorities find that it is primarily the intact metacarpal head which prevents the deformity.

This carefully written volume will prove of great value to the surgeon in the care of primary hand injuries.

CHIRURGIE DER INFEKTIONEN. MIT WEITGEHENDER BERÜCKSICHTIGUNG DER BEHANDLUNG. Prof. Dr. Rudolf Demel. Wien, Wilhelm Maudrich, 1947. $12.00.

This book on the surgery of infections is obviously written for the general surgeon. It is divided into two parts,—general and special. In the general section the problem of infections, anaesthesia, preoperative management, and general guiding principles of the treatment of infections are considered. In the special section the skull, head, spine and cord, neck, chest, abdomen, genitalia, and extremities receive separate treatment. However, of the 641 pages of the book, only ninety-four pages are assigned to the extremities. In a different part of the book, about ten pages cover the infections of the spine and cord and five pages deal with the management of the bones of the pelvis. There are 484 illustrations, some in color, which are well reproduced.

Throughout the text one encounters very few names familiar to the American reader. The book may be of interest to advanced medical students and to general surgeons who are familiar with the German language.

HEALTH INSURANCE IN THE UNITED STATES. Nathan Sinai, Dr. P.H., Odin W. Anderson, and Melvin L. Dollar. New York, The Commonwealth Fund, 1946. $1.50.

This short, factual monograph is another in the series published by the Committee on Medicine and the Changing Order of the New York Academy of Medicine. Voluntary group health prepayment plans in this country are traced from their beginnings in 1915. The authors have been fair in pointing out the shortcomings as well as the benefits of such plans, and they paint an accurate picture of present needs.

In any discussion of a health insurance program—whatever form it may take—the proponents of the plan have one end in view: to provide for the public protection against the costs of illness and a satisfactory distribution of all existing facilities. This book offers no utopian solution, but it merely sets forth various problems of organization, whose solution will determine the future of voluntary health insurance.

PHYSICAL MEDICINE IN GENERAL PRACTICE. Edited by Arthur L. Watkins, M.D. Philadelphia, J. B. Lippincott Company, 1946. $5.00.

This book is part of the American Practitioner's Series. Much credit is due the Editor, Dr. Arthur L. Watkins; and Dr. George Morris Pierson has written a timely foreword.

The Editor has compiled the writings of fourteen well-known experts in the field of physical medicine. Physical therapy, rehabilitation, and occupational therapy are well presented, especially the first two. It is a pleasure to read the clinical presentation of the various subjects comprising *Physical Medicine in General Practice*. It is written in medical language which any practitioner can understand. The technical aspect is explained in terms easily comprehended. Emphasis is placed upon the clinical application, and many chapters contain new material.

The chapter on minor injuries deals with athletic traumata. These have not received enough attention in former books on physical medicine. Electrodiagnosis is presented in a comprehensive way, and peripheral-nerve lesions are discussed in the light of new and experimental work done during the war. The care of the acute and convalescent poliomyelitic patient is well explained on a rational basis. Rehabilitation and reconditioning in Army hospitals, as well as in civilian hospitals, are discussed in two chapters which every doctor should read.

It is a credit to the Editor that so much information and very complete references are contained in 332 pages; and the attractive appearance of the book and good paper are a credit to the publishers. The only criticism that can be raised is the scarcity of illustrations and the poor choice used in selecting some of them.

This is the first book published on physical medicine since World War II, and it is interesting to compare it with the books written after World War I. Such a comparison shows the development of physical medicine from a technical modality to an integral part of medicine, both therapeutic and diagnostic.

Although this book is intended for general practitioners, it can also be recommended to specialists and students of physical medicine.

PHYSIKALISCHE MEDIZIN IN DIAGNOSTIK UND THERAPIE (Physical Medicine in Diagnosis and Treatment), 5 und 6 Auflage. Professor Dr. Med. Wolfgang Holzer. Wien, Wilhelm Maudrich, 1947. $9.00.

This book of 760 pages is one volume in a series on physical medicine, written by an eminently qualified Austrian physician. He was on the staff of the Physiology Department of the University of Vienna for many years, and his work has covered a variety of subjects. Since the author is a physician and an engineer, he is particularly qualified in physical medicine. In Europe, physical medicine includes electrocardiography, encephalography, roentgenotherapy, and radium therapy. In the United States, physical medicine excludes these subjects, but includes occupational therapy and rehabilitation.

Dr. Holzer has divided his subject into three divisions. In the first one, two chapters are devoted to physics and physiology. Here the author shows his training as an engineer. The various energies are treated

clearly and correctly, based upon thorough technical knowledge and great experience as a research worker.

The second division is devoted to the application of physical medicine in diagnosis and research. This is excellently covered in five chapters. Electrocardiography, electro-encephalography, spirometers, and electrodiagnosis are discussed very extensively; and there is also a chapter on rest and exercise.

The third division, of twenty-one chapters, deals with the application of physical medicine in therapeutics. Each chapter follows a pattern, convenient for quick orientation. The subject is explained from the physical standpoint first. Many pertinent biological and physiological facts are reported next. Reference is then made to a variety of therapeutic and diagnostic methods and to apparatus for the evaluation of circulation, the nervous system, metabolism, et cetera. Such forms of treatment as balneology, hydrotherapy, electrotherapy, and mechanotherapy are described in detail. The construction of the commonly used devices is explained. Their therapeutic applications are reviewed critically as to indications and contra-indications, as shown in diagrams. The photographs and drawings, made by an excellent artist, are particularly well chosen and help to clarify the subject considerably. The weakest parts of the book are the chapters on therapeutic exercises; reconditioning and occupational therapy are neglected.

Despite the almost insurmountable difficulties prevailing today in Austria, the editor has done a splendid piece of work. Printing and paper are of the highest quality. As all previous editions were published under the Nazi regime, the author has completely neglected the Anglo-American literature. This should be corrected in a subsequent edition. The German literature, on the other hand, is referred to exhaustively in twenty-two pages of bibliography.

This book is recommended for those specialists and students who have a good command of the German language, as Holzer's style is a rather complicated one.

SURFACE AND RADIOLOGICAL ANATOMY FOR STUDENTS AND GENERAL PRACTITIONERS. Ed. 2. A. B. Appleton, M.A., M.D. (Cantab.), W. J. Hamilton, M.D., D.Sc., F.R.S.E., and G. Simon, M.D., B.Ch., D.M.R.E. (Cantab.). Baltimore, The Williams and Wilkins Company, 1946. $7.00.

The authors of this book have presented a study of anatomy which, as the title suggests, goes beyond skeletal and postmortem examinations and, through the use of apparatus for special examinations and by the roentgenographic approach, helps to show how the living subject differs from the cadaver.

The illustrations, which are of excellent quality, include photographs of a member, as well as comparative drawings and roentgenograms, thereby showing the relationship between surface contours and deeper structures. Similarly, the text proceeds from surface examination to that of muscles, vessels, nerves, organs, and bones, including their relations to changing positions of the body. Individual variations in bodily type are emphasized.

The present edition has been rewritten and rearranged, and contains many new illustrations. The first section of the book deals with general anatomy and methods. The remainder is divided into six sections: the upper limb, the chest and back, the abdomen, the head and neck, the vertebral column, and the lower limb.

The presentation is clear, and the correlation of anatomy with clinical findings makes the book valuable.

MEDICAL ADDENDA. RELATED ESSAYS ON MEDICINE AND THE CHANGING ORDER. Committee on Medicine and the Changing Order, New York Academy of Medicine. New York, The Commonwealth Fund, 1947. $1.75.

These essays supplement the series of volumes issued by the Committee on Medicine and the Changing Order of the New York Academy of Medicine. In all, the Committee has published twelve volumes, and they form the foundation for the report of the Committee which summarizes the findings and points to a better future. As one of the Committee spokesmen points out: "The contents of these volumes are proof that the practice of medicine is changing from a private pursuit to a social obligation".

The essays in the present volume are able presentations of the most recent knowledge on such subjects as: Psychosomatic Medicine, Medical Social Work, Psychiatric Social Work, Chronic Diseases, and Rehabilitation and Convalescence. Of particular interest are the chapters on psychosomatic medicine and psychiatric social work. The psychiatrist, psychologist, and social worker are gradually coming to work as a trained, effective team; and, as time goes on, their combined efforts will be extremely beneficial, not only to the patient, but to our society as a whole.

Any one of the twelve monographs in this series is available through The Commonwealth Fund or the New York Academy of Medicine.

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